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11. Managing Risks of Extreme Weather

11.1 Socioeconomic context

Risks from human-caused climate change are convoluted with natural weather and climate variability, and are dominated by the exposure of wealth in coastal and other disaster-prone regions and vulnerabilities of poorer populations. The evolution of climate risk in the U.S. has been dominated by societal factors, rather than by changes to the actual weather and climate hazards. Deaths from weather disasters have decreased substantially since 1900, even as US population grew from 76 million in 1900 to over 331 million in 2020 (IM Gulkany, 2011). For example, the Galveston hurricane killed over 8,000 people in 1900 (0.01% of the US population), whereas the worst recent disaster, Hurricane Katrina in 2005, killed 1800 people (or 0.0006% of the US population) (NOAA, 2025; USCB, 2025).

Technological advances have substantially reduced losses from extreme weather events. Early warning systems, satellite monitoring, and improved weather forecasting have reduced deaths, although exact numbers are hard to quantify (T Deryugina and SM Hsiang, 2023). US weather forecasting has been estimated to reduce losses from weather events with an annualized benefit of \$31.5B, protecting lives, property, and supporting agriculture and transportation (NRC, 2010). Improved hurricane forecasts have reduced pre- and post-landfall spending, with annual per hurricane cost reductions estimated at \$5B (NBER, 2024).

Infrastructure improvements have contributed to substantial reductions in losses from extreme weather events. Building codes, such as those implemented in Florida after Hurricane Andrew (1992) have reduced losses by ensuring structures can withstand high winds and floods. Homes built after 2002 showed minimal damage during Hurricane Michael (2018), unlike older homes (FEMA, 2020). Sea walls, like the Galveston Seawall, protect against wave action and storm surge. The New Orleans Hurricane and Storm Damage Risk Reduction System successfully mitigated storm surge during Hurricane Isaac (2012) (BMI, 2013). Inland dams in the US help control flooding by storing excess water during heavy rains. It is estimated that the Tennessee Valley Authority (TVA) dams prevent about \$309M in annual flood damage in the TVA region and along the Ohio and Mississippi Rivers (TVA, 2025). During Hurricane Helene (2024), TVA's strategies prevented approximately \$406M in potential damages (APPA, 2024).

11.2 Data challenges

Since 1980, NOAA has provided a count of annual U.S. weather-related disasters that it estimates to have exceeded \$1Billion (inflation adjusted), showing a substantial increase starting in 2008. NOAA and other government officials have cited the upward trend in the Billion Dollar Disaster series as evidence that climate change is making extreme weather worse (R Pielke Jr., 2024). But over time, population and wealth have increased dramatically in the US, so when an extreme weather or climate event occurs, there is more damage even if there is no underlying trend in the frequency or intensity of extreme weather. Pielke Jr. (2024) demonstrates that losses per weather disaster are down by about 80% since 1980, as a proportion of GDP. Pielke Jr. (2024) also argued that in addition to relying on opaque data sources and unreported adjustments NOAA failed to normalize its Billion Dollar Disaster data series properly for changes in population exposure and

wealth. In May 2025 NOAA announced it has withdrawn the billion-dollar disaster product from publication (R Pielke Jr., 2025).

In summary, trends in losses from extreme weather and climate events are dominated by population increases and economic growth. Technological advances such as improved weather forecasting and early warning systems have substantially reduced losses from extreme weather events. Better building codes, flood defenses, and disaster response mechanisms have lowered economic losses relative to GDP. And finally, the US economy's expansion has diluted the relative impact of disaster costs, as seen in the comparison of historical and modern GDP percentages.

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2. National Hurricane Center, “Costliest U.S. Tropical Cyclones Tables Updated,” *NOAA National Hurricane Center*, accessed May 8, 2025, <https://www.nhc.noaa.gov/outreach/history/>.
3. U.S. Census Bureau, Decennial Census by Decade, accessed May 8, 2025, <https://www.census.gov/programs-surveys/decennial-census/decade.html>.
4. Tatyana Deryugina and Solomon M. Hsiang, *Does the Environment Still Matter? Daily Temperature and Income in the United States*, NBER Working Paper No. 31361 (Cambridge, MA: National Bureau of Economic Research, June 2023), <https://www.nber.org/papers/w31361>.
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8. Battelle Memorial Institute, *Final Independent External Peer Review Report: Hurricane Isaac (2012) Assessment*, prepared for U.S. Army Corps of Engineers, New Orleans District, December 2013, <https://www.mvn.usace.army.mil/Portals/56/docs/PD/PeerReview/TCN13-003HurriIsaacAssessIEPRFinal.pdf>.
9. Tennessee Valley Authority (TVA), *Flood Management*, accessed May 8, 2025, <https://www.tva.com/environment/managing-the-river/flood-management>.
10. American Public Power Association, “TVA Flood Mitigation Strategies Prevented Approximately \$406 Million in Potential Damages,” *Public Power Current*, March 7, 2024, [HYPERLINK "https://www.publicpower.org/periodical/article/tva-flood-mitigation-strategies-prevented-approximately-406-million-potential-damages"].
11. Roger Pielke Jr., “Scientific Integrity and U.S. ‘Billion Dollar Disasters’,” *npj Natural Hazards* 1 (2024): Article 12, [HYPERLINK "https://www.nature.com/articles/s44304-024-00011-0" \t "_new"].
12. Roger Pielke Jr., “RIP NOAA’s Billion Dollar Disasters,” *The Honest Broker (Substack)*, May 8, 2025, [HYPERLINK "https://rogerpielkejr.substack.com/p/rip-noaas-billion-dollar-disasters" \t "_new"].

Fig 8.4.5

Number of days $\geq 95^{\circ}\text{F}$

Line	Dashed	Dash	Dash	solid	solid	solid	solid
	PacSW	PacNW	4Crns	NPIns	SPIns	UMidW	OhVly
1899-04	226.87	52.44	177.12	48.23	240.6	17.61	71.75
1905-10	246.06	58.9	156.64	43.43	252.04	12.52	36.88
1911-16	199.73	46.82	144.22	46.2	315.36	29.34	109.8
1917-22	249.24	60.09	161.85	63.02	287.09	19.65	73.52
1923-28	243.99	62.09	160.34	41.87	304.58	13.4	61.64
1929-34	262.64	69.52	185.1	106.45	352.83	53.69	133.09
1935-40	261.61	69.43	199.82	115.18	337.97	42.35	106.54
1941-46	226.36	52.44	167.46	52.52	279.87	14.63	74.02
1947-52	234.63	40.2	182.8	57.34	307.28	19.59	54.35
1953-58	230.37	45.29	193.15	60.83	365.82	21.53	90.8
1959-64	245.47	56.6	184.33	67.11	273.38	10.24	34.97
1965-70	248.82	60.42	157.92	54.57	234.28	8.87	29.52
1971-76	243.4	56.28	161.78	60.7	192.9	14.34	26.07
1977-82	238.95	51.77	182.54	50.11	293.96	11.52	43.48
1983-88	238.61	52.9	166.58	73.72	250.86	28.1	63.76
1989-94	233.65	52.69	176.58	41.43	200.48	5.86	25.61
1995-00	236.45	52.28	186.83	46.05	285.7	6.73	32.24
2001-06	282.35	71.74	214.31	73.19	244.03	9.83	30.58
2007-12	271.04	54.61	203.74	53.55	290.75	9.86	53.07
2013-18	292.46	72.52	200.35	41.8	246.15	3.9	15.35
2019-24	317.1	85.76	242.01	62.73	296.85	7.41	25.31

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125.58	9.14	121.36
91.13	4.85	113.43
129.88	13.78	132.27
110.96	11	130.91
138.61	8.6	131.52
163.7	17.5	169.74
126.03	10.49	162.16
127.49	12.25	127.91
124.37	12.05	133.31
144.8	14.18	151.93
83.47	5.63	123.58
68.56	5.02	109.31
41.83	3.54	99.8
116.47	4.34	128
104.28	11	124.6
75.27	6.63	102.48
107.37	7.28	124
63.89	8.93	125.66
125.07	9.57	136.11
68.19	5.14	118.27
92.85	8.16	143.76

Introduction

This document ~~originated had its origin in an initiative undertaken in late March 2025 when by Secretary Wright to assemble assembled an independent team to write a brief report for him on issues in climate science relevant for energy policymaking, with particular focus on the question of whether carbon dioxide emissions pose a danger to endanger the US public. The team authors of this report agreed on the usefulness of such a document and agreed to undertake the work on the condition that there was to would be no editorial oversight by the Secretary, the Department of Energy, or any other government personnel. This condition has been honored throughout the process and the writing team has worked with full independence.~~

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The team began working in early April with a ~~final submission~~ deadline of May 28. ~~Because of the~~ short timeline and the technical nature of the material ~~meant we have not tried to produce that we could not~~ comprehensively review of all topics. While the report is intended to be accessible for non-experts, we ~~deliberately have~~ omitted some introductory or explanatory material that can easily be accessed elsewhere. Nor have we attempted to survey entire literatures related to the topics selected for focus covered. The scientific and technical material herein is just a sample of the only samples vast literature on climate change but is, we believe, more than sufficient to establish our conclusions.

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~~{The team writing this report was not involved in, nor briefed on, any Administration plans or administrative processes related to a potential challenge to the 2009 EPA CO₂ Endangerment Finding. During the writing of this report we received no information about the Administration's plan on that matter. We were asked, however, to include some information related to the role of US motor vehicles in global climate change, since that is an issue of relevance to the Department of Energy.}~~

The writing team wishes to express its grateful thanks to Secretary Wright for the opportunity to prepare this report and for his support for independent scientific inquiry.

Commented [TF3]: You could say it's public knowledge that the EPA announced in March 2025 that it was "kicking off a formal reconsideration of the 2009 Endangerment Finding in collaboration with the Office of Management and Budget (OMB) and other relevant agencies. EPA also intends to reconsider all of its prior regulations and actions that rely on the Endangerment Finding." [HYPERLINK "<https://www.epa.gov/newsreleases/trump-epa-kicks-formal-reconsideration-endangerment-finding-agency-partners>"]

I think you can acknowledge that this effort is designed to inform the EPA's policymaking process.

(May 14 RM edit: some wording changes, removed orphan Figure 12.1, corrected Gasparini and other references)

12 Mortality risks from heat and cold temperature extremes

12.1 Heat and cold risks

Changes in temperature extremes are among the most certain impacts expected in a warming world. Extreme heat events are expected to become more frequent while extreme cold events become less frequent. This pattern The greatest confidence for impacts from global warming is an increase in extreme heat events and a decrease in extreme cold events; this has been observed is evident in the historical period (as discussed in Section XX Chapter 7) and is also expected to intensify continue with sustained further warming.

Mortality from during heat extremes is typically caused by heat stroke and heat exhaustion, while, m Mortality from during cold extremes is typically caused by hypothermia and heart strain. It is well known that global mortality is substantially greater for extreme cold conditions than for extreme heat conditions.^{1,2a} Unlike with heat-related mortality, cold-weather risks act in even at moderately cold conditions (Gasparini et al. 2015, Lee and Dessler 2023). A 13-country study of 74 million deaths from 1985 to 2012 estimated that, on average, 7.7% of deaths were attributable to sub-optimal temperatures, of which 7.4% were attributable to cold and only 0.4% were attributable to heat (Gasparini et al. 2015). In other words cold weather killed 18.5 times as many people as did hot weather.

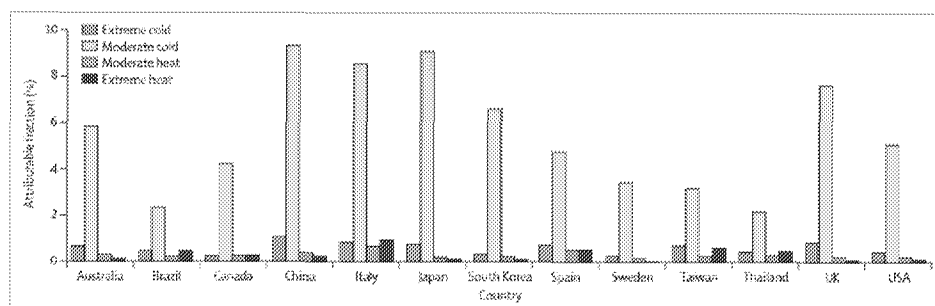


Figure 12.1. Mortality attributable to extreme and moderate cold and heat by country. Source: reproduced from Gasparini et al. (2015).

¹ Qi Zhao et al., “Global, Regional, and National Burden of Mortality Associated with Non-Optimal Ambient Temperatures from 2000 to 2019: A Three-Stage Modelling Study,” *The Lancet Planetary Health* 5, no. 7 (July 2021), [https://doi.org/10.1016/s2542-5196\(21\)00081-4](https://doi.org/10.1016/s2542-5196(21)00081-4).

² <https://ourworldindata.org/part-one-how-many-people-die-from-extreme-temperatures-and-how-could-it-change-in-the-future>

^{2a} <https://ourworldindata.org/part-one-how-many-people-die-from-extreme-temperatures-and-how-could-it-change-in-the-future>

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Figure 12.1 shows the distribution of results from Gasparini et al. (2015) by country. For the United States the fraction of deaths attributable to temperature was 5.9%, of which 5.5% was due to cold, thus cold weather killed 14 times as many people as hot weather. Specifically, with regards to the specific to the U.S., extreme heat and extreme cold both kill hundreds of people each year; however, different approaches to assessing heat/cold mortality produce different results. The Center for Disease Control (CDC) National Center for Health Statistics Compressed Mortality Database, which is based on death certificates, indicates that about twice as many people die of “excessive cold” conditions in a given year than of “excessive heat.”^{4,5}

There is strong evidence that people adapt to weather risks. A 2015 epidemiological study of deaths⁴ as published in *The Lancet* found that cold-related deaths in the U.S. were about a factor of fifteen higher than heat-related deaths.⁶ However, the study did not adjust for the seasonal cycle in mortality rates, which tend to increase during the winter months due to non-weather factors like influenza.⁷ A more recent paper Lee and Dessler (2023) found reported that 86% of temperature-related deaths across 40 cities in the U.S. are were due to cold-related mortality, and that due to adaptation the relative risk of death declined in hot and cold cities alike as seasonal temperatures increased. Allen and Sheridan (2018) found that short, early-season cold events were 2 to 5 times deadlier than hot events, but the mortality risk of both cold and hot extremes drops to nearly zero if the events occur late in the season.⁸

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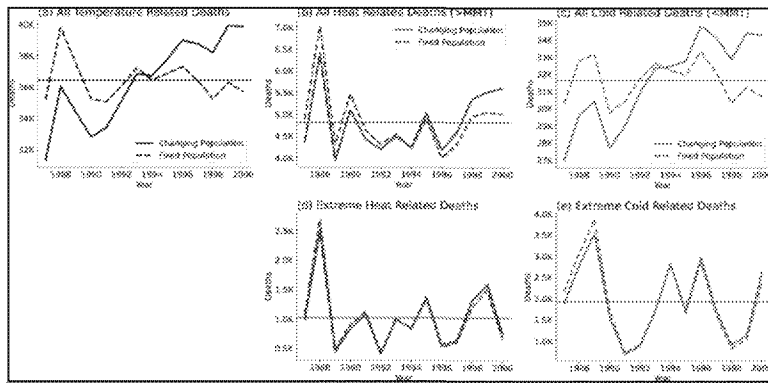
⁴ Ross R., Schellert et al., “The Direct Footprint of Climate Change from Cancers to Diseases to People,” *Science*, 354, no. 6313 (November 11, 2016), 27621. [HYPERLINK “https://doi.org/10.1126/science.aaf7671”]...

⁵ Rachel H. Ainsley, Scott E. Hurler, J. Darius Wilson, Randa A. Mason, and Brandon Saloner, “Trends in Polypharmacy-Associated Deaths Involving Opioids, Stimulants, and Benzodiazepines by Race and Ethnicity in the U.S., 2007-2021,” *Health Affairs*, Jan 2, no. 3 (2024), 2024-2025249. [HYPERLINK “https://doi.org/10.1001/jamanetworkopen.2024.8249”]...

⁶ James G. Thompson et al., “Climate Change and Health: Health and Climate Change Policy Responses to Present Public Health,” *The Lancet*, 386, no. 10006 (November 7, 2015), 1861-1914. [HYPERLINK “https://doi.org/10.1016/S0140-6736(15)00544-6”]...

⁷ Rob Hansen, “Which Kills More People: Extreme Heat or Extreme Cold?” *Weather Underground*, January 22, 2019. [HYPERLINK “https://www.weatherunderground.com/463W-Which-Kills-More-People-Extreme-Heat-or-Extreme-Cold”]...

⁸ Luke Bonanville et al., “Deaths Attributable to Heat and Cold: Comparison of Data Sources and Implication of Inconsistency,” *Geofhealth*, 8, no. 3 (March 2024), 2403031606392. [HYPERLINK “https://doi.org/10.1029/2023GH000799”]...



Caution Figure 12.1: Time series of temperature-related deaths across all 106 cities. (a) The solid line represents total temperature-related deaths, while the dashed line indicates temperature-related deaths with a fixed population (average population from the 1987–2000 period). (b) Similar to (a), but for heat-related deaths. (c) Similar to (a), but for cold-related deaths. (d) Time series of deaths occurring in temperatures above the 97.5th percentile. (e) Similar to (d), but for temperatures below the 2.5th percentile. From <https://onlinelibrary.wiley.com/doi/10.1029/2023GH000799>

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The IPCC AR6 Working Group 2 Chapter 16.2.3.5 states how heat-related mortality is declining over time⁹

“Heat-attributable mortality fractions have declined over time in most countries owing to general improvements in health care systems, increasing prevalence of residential air conditioning, and behavioral changes. These factors, which determine the susceptibility of the population to heat, have predominated over the influence of temperature change.”

A 2011 study of 40 major US cities between 1975 and 2001, found that heat-wave mortality had decreased, in spite of rising temperatures, due to adaptation.⁴⁶ Davis et al. (2003) examined heat-related mortality in 28 U.S. cities from the 1960s to the end of the 1990s and found that heat-related mortality declined by three-quarters over the sample period. Bobb et al. (2014) examined mortality data for 106 million people in over 100 cities U.S. cities and found a 60% decline in average heat-related mortality over the period 1987–2005, from 51 per thousand deaths to 19. They furthermore found that the greatest drop was among seniors over the age of 75. In a study of

⁹ D. J. Nott et al., “Eddy Risks Across Sectors and Regions,” in *Climate Change 2022: Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (Geneva, CH: Intergovernmental Panel on Climate Change, 2021), 3411–3538.

⁴⁶ Keith L. Ingman, Carolyn W. Fenner, and John W. Jones, “Climate Change Impact and Adaptation Assessment: A Guide for Coastal Resource Managers,” *Wetters, Climate, and Society*, 3, no. 4 (October 2011): 224–249.

[HYPERLINK “<https://doi.org/10.1175/WCAS-D-11-00055.1>”]

42 million deaths in 211 U.S. cities from 1962 to 2006. Nordin et al. (2015) found a more than 90 percent decline in the risk of mortality from excess heat.

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In the context of large declines in heat-related mortality, By-by reducing mortality from cold events and adapting to heat extremes, rising temperatures are associated with a net saving of lives.

The IPCC AR6 Working Group 2 Chapter 16.2.3.5 states how heat-related mortality is declining over time.¹¹

“Heat-attributable mortality fractions have declined over time in most countries owing to general improvements in health care systems, increasing prevalence of residential air conditioning, and behavioral changes. These factors, which determine the susceptibility of the population to heat, have predominated over the influence of temperature change.”

It is both disappointing and telling to see how the IPCC misrepresents the situation in its AR6 Synthesis report. Section A.2.5 of that document states: “In all regions increases in extreme heat events have resulted in human mortality and morbidity (very high confidence).” But it is silent on the larger decline of deaths during extreme cold events.

12.2 The importance of adaptation

The observed decline in US heat-related mortality has been specifically attributed to adaptation. Wang et al. (2018) exploited the spatial variability of heatwave-related mortality across 209 U.S. cities from 1962 to 2006. While simple correlation appeared to imply an increase in mortality risk during heatwaves, accounting for adaptation to heatwave intensity caused the effect to fall to near zero and become statistically insignificant. They used the results of their epidemiological model to project heat-related mortality out to 2050 under four RCP warming scenarios (including RCP8.5) with and without adaptive behavior. Assuming people continue to adapt to the heatwave risks in the regions in which they live Wang et al. project not only no increase in heat-related mortality but an overall decrease for the US as a whole. They conclude that “Ignoring adaptation would result in a substantial overestimate of future mortality related to heat waves... Accounting for adaptation, the overall heat-related mortality by 2050 would not change substantially over time compared to 2006.”

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Mortality risks and energy costs

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A 2016 study of US long term mortality risks associated with temperature variations (Barreca et al. 2016) showed that increases in mortality across the US are associated both with cold weather and hot weather. But over time, the introduction of electricity and the adoption of central heating and air conditioning (AC) dramatically reduced both risks, especially those associated with hot

¹¹ B. O'Neill et al., “Key Risks Across Sectors and Regions,” in *Climate Change 2022: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (Geneva, CH: Intergovernmental Panel on Climate Change, 2021), 2411–2438.

weather. Prior to 1960, a day above 90°F (32°C) added 2.2 percent to the average mortality risk rate, but after 1960 the same weather added only 0.3 percent to mortality risk, an 85 percent reduction. Prior to 1960 temperatures below 39°F (4°C) added about 1 percent to mortality risk but after 1960 the same weather only added about half that amount. Adaptation through conventional household improvements dramatically reduced public vulnerability to weather extremes. The entire reduction in hot weather mortality was attributable to widespread adoption of indoor AC, which depended on the availability of reliable and affordable electricity.

The corollary of this finding is that the use of heating and cooling systems depends on energy being affordable. Doremus et al. (2022) showed that wealthy and poor households in the US adjust their energy expenditures at similar rates in response to moderate temperature swings, but not in response to extreme temperature swings. When temperatures swing to very cold levels (< 5°C) energy spending in high-income households rises by 1.2 percent but in low-income households by only 0.5 percent. On very hot days (>30°C) electricity spending in high-income households rises by 0.5 percent but does not change at all in low-income households. The latter result is observed even in subsamples where all households have AC. The implication is that even with widespread adoption of home heating and cooling systems, inability to afford energy leaves low-income households exposed to weather extremes.

Barroca, Alan, Karen Clay, Olivier Deschenes, Michael Greenstone, and Joseph S. Shapiro, "Adapting to climate change: The remarkable decline in the US temperature mortality relationship over the twentieth century," *Journal of Political Economy*, 2016, 124 (1), 105–159.

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J.M. Doremus, I. Jacqz and S. Johnston (2022), "Sweating the energy bill: Extreme weather, poor households, and the energy spending gap," *Journal of Environmental Economics and Management*, doi: [HYPERLINK "<https://doi.org/10.1016/j.jeem.2022.102609>"].....

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Nordio, Francesco, Antonella Zanobetti, Elena Colicino, Itai Kloog and Joel Schwartz (2015), "Changing patterns of the temperature–mortality association by time and location in the US, and implications for climate change," *Environment International*, Volume 81, pp 80–86 [HYPERLINK "<https://doi.org/10.1016/j.envint.2015.04.009>"].

Wang, Yan, Francesco Nordio, John Naim, Antonella Zanobetti and Joel D. Schwartz (2018) "Accounting for adaptation and intensity in projecting heat wave-related mortality" *Environmental Research* 161 pp. 464–471. [HYPERLINK "<https://doi.org/10.1016/j.envres.2017.11.049>"]

Bobb JF, Peng RD, Bell ML, Dominici F. (2014) Heat-related mortality and adaptation to heat in the United States. *Environmental Health Perspectives* 122:811–816. [HYPERLINK "<https://ehp.niehs.nih.gov/doi/full/10.1289/ehp.1307392>"]

Davis, Robert E., Paul C. Knappenberger, Patrick J. Michaels and Wendy M. Novicoff (2003) "Changing Heat-Related Mortality in the United States" *Environmental Health Perspectives* 111(14) November 2003 pp. 1712–1718.

Lee, Jangho and Andrew E. Dessler(2023) Future Temperature-Related Deaths in the U.S.: The Impact of Climate Change, Demographics, and Adaptation. *Geohealth* 7(8) e2023GH000799 [HYPERLINK "<https://doi.org/10.1029/2023GH000799>"]

Allen, M.J., Sheridan, S.C. Mortality risks during extreme temperature events (ETEs) using a distributed lag non-linear model. (2018) *International Journal of Biometeorology* 62, 57–67 (2018). [HYPERLINK "<https://doi.org/10.1007/s00484-015-1117-4>"]

4 Anthropogenic Radiative Forcing Human influences on the climate

4.1 Components of anthropogenic radiative forcing and their history to date

4.1.1 Historical radiative forcing

A changing climate has been the norm throughout the Earth's 4.6-billion-year history. The Earth's temperature and weather patterns change naturally over timescales ranging from decades to millions of years. Natural variations in the surface climate originate in two ways. Internal climate fluctuations associated with circulations in the atmosphere and ocean produce exchanges of energy, water, and carbon between the atmosphere, oceans, land, and ice. External influences on the climate system include variations in the energy received from the sun and the effects of volcanic eruptions. Human activities influence climate through changing land use and land cover. Humans are also changing the composition of the atmosphere by increasing the emissions of CO₂ and other greenhouse gases and by altering the concentrations of aerosol particles in the atmosphere.

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The earth is warmed by the sunlight it absorbs and cooled by the radiative heat it emits to outer space. Averaged over the Earth's surface, each of these processes involve power flows of about 240 Watts per square meter (W/m²). When they are in balance, there are no net external causes of warming or cooling. Human (and some natural) influences on the climate alter this balance and so cause the climate to change.

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Influences on the Earth's energy balance at the top of the atmosphere are quantified by "radiative forcing", the extent to which they disturb the warming/cooling balance; a positive forcing warms while a negative forcing cools. The IPCC's estimated history of major components of radiative forcing since 1750 is shown in the following two figures from its IPCC AR6.

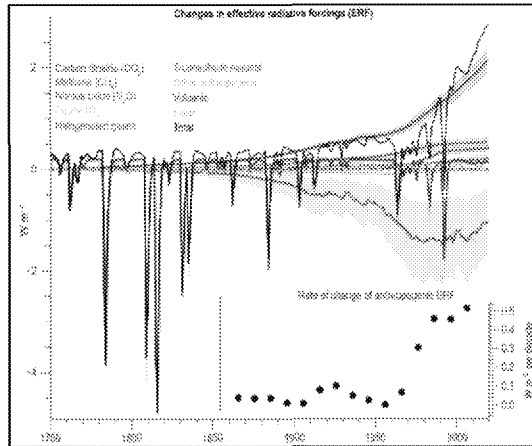


Figure 4.1.1: IPCC estimates of radiative forcing components over time. Source: [[HYPERLINK "https://www.ipcc.ch/report/ar6/wg1/figures/chapter-2/figure-2-10/"](https://www.ipcc.ch/report/ar6/wg1/figures/chapter-2/figure-2-10/)]

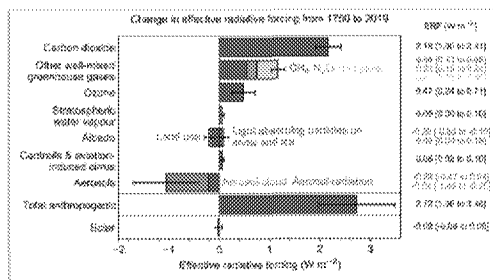


Figure 4.1.2 IPCC estimates of radiative forcing component changes from 1750 to 2019. Source: [[HYPERLINK "https://www.ipcc.ch/report/ar6/wg1/figures/chapter-7/figure-7-6/"](https://www.ipcc.ch/report/ar6/wg1/figures/chapter-7/figure-7-6/)]

These graphs show that the total radiative forcing is comprised of both natural and anthropogenic components. Carbon dioxide is the largest human influence on the climate and the one most relevant to the effects of energy-using systems like motor vehicles. It exerts a warming influence by decreasing the cooling power of the atmosphere. Its emissions of CO₂ are accumulating in the atmosphere, as described in the following section, so that the warming influence is increasing. It exerts a warming influence by decreasing the cooling power of the atmosphere. Other greenhouse gases (methane, nitrous oxide, halogens, and ozone) which act similarly, currently adding another 75%

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to CO₂'s warming. Aerosols exert a cooling effect, although with large uncertainties in the way they catalyze the formation of reflective clouds. As a result, understanding of the causes of recent warming requires not just identifying the warming effects of CO₂, but also the more uncertain cooling effects of sulfate aerosols.

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The IPCC views the role change in the radiative forcing of by the sun as to be negligible, based on their preference for reconstructions that imply minimal solar change since preindustrial times. Connolly *et al.* (2021) reviewed 16 sixteen different Total Solar Irradiance (TSI) reconstructions in the literature covering the 1600-2000 interval; they which vary in their implications from almost no change in TSI to a relatively large upward trend. Those authors note They point out that the variation in TSI reconstructions combined with variations in surface temperature reconstructions implies allows for pairings can be found that are consistent with either no or most 20th century warming being attributable to the sun. A particularly thorny issue is the gap in the TSI data between 1989 and 1991 due to a delay in the launch of a monitor after following the Space Shuttle Challenger disaster on January 28 1986. That which prevented a replacement satellite from being launched in time to overlap with, and its readings to be intercalibrated with, the prior system (Zacharias 2014, Scafetta et al. 2019). The question of whether there is an upward trend in TSI over 1978 to 2018 comes down to how the missing data in that gap are is filled. That being the case it is noteworthy that Zacharias (2014) observes the solar research community has been motivated by a desire to downplay any potential role of the sun in climate change so as not to detract from arguments for greenhouse gas abatement

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A conclusive TSI time series is not only desirable from the perspective of the scientific community but also when considering the rising interest of the public in questions related to climate change issues, thus preventing climate skeptics from taking advantage of these discrepancies within the TSI community by e.g., putting forth a presumed solar effect as an excuse for inaction on anthropogenic warming.

(Zacharias 2014)

~~I'M NOT THRILLED WITH THE ZACHARIAS REF THIS SEEMS LIKE CHEAP POINTS SCORING, AND ATTRIBUTING MOTIVES TO OTHER PEOPLE IS A BAD MOVE. I THINK THE STATEMENT FROM CONNOLLY IS BETTER~~

~~Connolly et al. (2023) found that the IPCC's consensus statements on the Sun/climate debate is an issue wheresolar forcing the IPCC's consensus statements were prematurely achievedformulated through the suppression of dissenting scientific opinions.~~

The other natural radiative forcing component is largely volcanic aerosols, which exert an episodic cooling effect. Box 4.1 in the IPCC AR6 Report addresses the climate impact of volcanic eruptions, noting three explosive volcanic eruptions that occurred in the first half of the 19th century. This included the 1815 Tambora eruption that resulted in the 'year without summer', with multiple harvest failures across the Northern Hemisphere. There is uncertainty about the sign of the relatively small forcing due to the submarine volcano Hunga Tonga which erupted in 2022 (Jenkins et al. 2023, Schoeberl et al. 2024)

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The anthropogenic forcing component was negligible before about 1900 and has increased steadily since, rising to almost 3 W/m² today. However, this is still only about 1 percent of the unperturbed radiation flows, making it a challenge to isolate the effects of anthropogenic forcing; since state-of-the-art satellite estimates of global radiative energy flows are only accurate to a few W/m² Watts per sq. meter. Natural sources of global energy imbalance other than volcanoes are not included in these graphs because they remain largely unknown.

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4.1.2 Future radiative forcing

Carbon dioxide's warming influence depends upon how much "extra" CO₂ accumulates in the atmosphere- i.e., its concentration above 280 ppm. The CO₂ level as recorded at the Mauna Loa observatory in Hawaii is generally used as the representative global average concentration. The data are available online at [[HYPERLINK "https://gml.noaa.gov/ccgg/trends/index.html"](https://gml.noaa.gov/ccgg/trends/index.html)]. The concentration was about 316 ppm at the start of the record in 1959 and is now about 425 ppm, a 34 percent increase.

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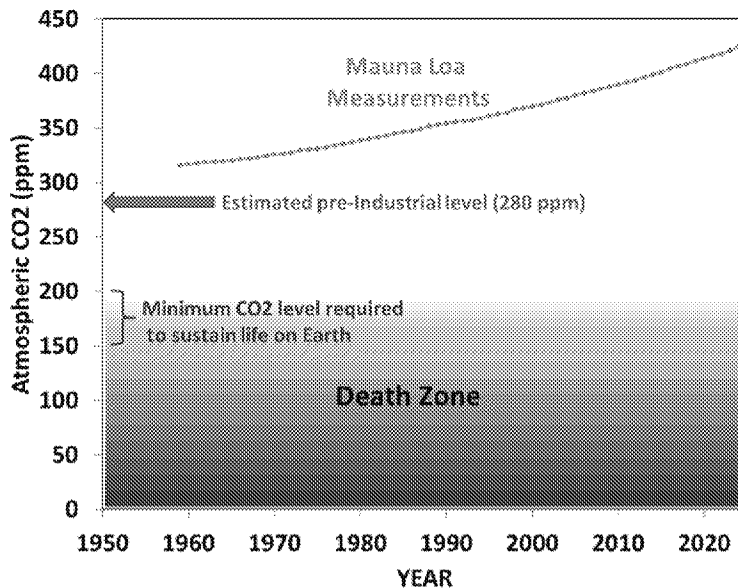


Fig. 4.1.3 Yearly average atmospheric CO₂ concentrations (1959-2024) measured at Mauna Loa, HI (green) compared to the estimated pre-Industrial CO₂ concentration of 280 ppm, and the estimated minimum levels required to sustain life on Earth (150 to 200 ppm). Need source

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The annual increase in concentration is only about half of the CO₂ emitted because land and ocean processes absorb "excess" CO₂ at a rate approximately 50% of the human emissions. Thus, future concentrations, and hence future human influences on the climate, therefore depend upon two components: (1) future rates of global human CO₂ emissions, and (2) how fast the land and ocean remove extra CO₂ from the atmosphere. We discuss each of these in turn.

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4.2 The carbon cycle and future emission scenarios and the carbon cycle

4.2.1 Emission scenarios

Assessing the future dangers of future GHG emissions requires assumptions about what those emissions will be. Future emissions, and hence human influences on the climate,

will depend upon future demographics, economic progress, regulation, and the energy and agricultural technologies in use. Various assumptions about each of those lead to projections of greenhouse gas emissions and concentrations, aerosol concentrations, and changes in land use, which ultimately can be combined into assumptions about anthropogenic radiative forcing.

Because of the great uncertainties about these many factors in the decades to come, instead of making precise predictions of future concentrations, the IPCC has created various sets of scenarios meant to span a plausible range of possibilities for population, economy, technology, and so on. Recent versions of the scenarios are labeled by a number indicating the anthropogenic radiative forcing expected in 2100 under that scenario. Thus, a scenario labeled with a "6" corresponds to 6 W/m^2 of human-induced radiative forcing (warming) at the end of the century. (Recall current anthropogenic radiative forcing is about 2.7 W/m^2 .)

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Although the IPCC does not put its emission scenarios forward as forecasts, they are often treated as such. Comparisons of past scenario groups against observations shows a tendency for IPCC emission projections to overstate actual subsequent emissions. For the IPCC Third and Fourth Assessment Reports a set of emission projections from the *Special Report on Emission Scenarios* were used, and hence were referred to as the SRES scenarios. McKittrick *et al.* (2012) showed that, when converted to per capita terms, the SRES scenario emissions distribution was skewed upwards and incompatible with observed trends. McKittrick and Wood (2013) further showed that global energy market dynamics constrained global per capita CO_2 emissions to an extent not reflected in IPCC scenarios. The bias of the SRES scenarios was confirmed by the later analysis in Hausfather *et al.* (2019) who showed that observed atmospheric CO_2 concentrations tracked the low end of the SRES range.

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For the Fifth Assessment Report the IPCC developed a new set of scenarios called the Representative Concentration Pathways (RCP). These were identified by a number representing the increase in forcing and were thus called RCP2.6, RCP4.5, RCP6.0 and RCP8.5. RCP2.6 (implying an anthropogenic gain radiative forcing in 2100 of 2.6 W/m^2 Watts per square meter) projects a GHG concentration pathway which leading to implies warming remains well below 2°C . At the other end of the scale RCP8.5 is an extreme outcome implying nearly 5°C warming just in this century.

RCP8.5 came to be referred to as the no-policy baseline, or "business-as-usual" scenario. In both the academic literature and popular media RCP8.5 came to be referred to as the no-policy baseline, or "business-as-usual" scenario. It was therefore used in this way to generate the reference outcome supposedly representing the 21st century world in the absence of emission reduction policies. But RCP8.5 was intended as a low-probability high emissions scenario and its usage as a business-as-usual baseline has been

criticized as grossly misleading.¹ Hausfather and Peters (2020) writing in a commentary in *Nature* magazine, pointed out that RCP8.5 was developed as an extreme worst-case, and its misuse as a "business as usual" baseline has resulted in a large number of misleading studies and media reporting.: QUOTE NOT NEEDED

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~~RCP8.5 was intended to explore an unlikely high-risk future. But it has been widely used by some experts, policymakers and the media as something else entirely: as a likely 'business as usual' outcome. A sizeable portion of the literature on climate impacts refers to RCP8.5 as business as usual, implying that it is probable in the absence of stringent climate mitigation. The media then often amplifies this message, sometimes without communicating the nuances. This results in further confusion regarding probable emissions outcomes, because many climate researchers are not familiar with the details of these scenarios in the energy modelling literature.~~

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(Hausfather and Peters 2020)

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The implausibility of the RCP8.5 scenario was examined by Burgess *et al.* (2021). They noted that RCP8.5 has already diverged from observed trends in energy use trends, and the near future trends diverge sharply from those of the International Energy Agency (IEA), which provides market-based projections of energy use for coming decades. The IEA trends, which are based on plausible extrapolations of current economic and demographic trends, and the results run below the entire envelope of RCP projections, implying not only that RCP8.5 is dubious, but that even lower emission scenarios are looking unlikely. Burgess *et al.* comment (p. 8):

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~~Beyond 2040, if the trends anticipated by energy agency forecasts continue, carbon intensity will continue diverging from AR5 and SSP baselines—especially from higher-emissions scenarios such as RCP8.5, due to the assumptions about fossil fuel expansion in these scenarios that are increasingly implausible.~~

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Widespread use of RCP8.5 has created an alarmist caused a bias in the climate impacts literature towards alarmism in the climate impacts literature. The extent of this problem was confirmed in a literature analysis by Pelke Jr. and Ritchie (2020). They found (p. 32) that some 16,800 scientific papers published between 2010 and 2020 some 16,800 scientific papers had been published using used the RCP8.5 scenario, and (p. 16) that with about 4,500 of the articles (p. 16) linked RCP8.5 with to the concept of "business-as-usual". Their analysis sy provided analyses of howed how RCP8.5 was misused not only by individual researchers, but also by influential science agencies like the IPCC and the US National Climate Assessment (USNCA), which has directly led to misleading coverage in prominent media outlets. They provide the following example (p. 30):

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¹ This extreme scenario is useful for modelers, since a large forcing generates a large response (warming) making it easier to assess a model's sensitivity. But that's very different than claiming it is a plausible future.

The USNCA employed RCP8.5 as a baseline scenario, despite warning against such use, and compared it to RCP4.5 throughout its report to generate quantitative economic estimates of the benefits of mitigation. In a front-page story, the *New York Times* promoted the report's misuse of RCP8.5 as a baseline scenario:

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"A major scientific report issued by 13 federal agencies on Friday presents the starkest warnings to date of the consequences of climate change for the United States, predicting that if significant steps are not taken to rein in global warming, the damage will knock as much as 10 percent off the size of the American economy by century's end."

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Pielke and Ritchie (2020) reported new studies using RCP8.5 were appearing in the literature at a rate of about 20 per day with about two per day specifically linking RCP8.5 and "business as usual." They conclude (p. 34) that the climate research community has spent a decade "committing scientific resources to science fiction" and that "The scientific literature has become imbalanced in an apocalyptic direction." (emphasis added):

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~~"Derived estimates from RCP8.5 as "business as usual" such as future climate impacts, the impacts avoided from mitigation and the cost effectiveness and benefits of mitigation have no real-world meaning... The scientific literature has become imbalanced in an apocalyptic direction.~~
(Pielke Jr. and Ritchie p. 34)

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The IPCC developed a new set of scenarios for the AR6, later converted the RCP scenarios to the "Shared Socioeconomic Pathway" or SSP scenarios, but these have continued the pattern of bias shown with the RCP and SRES scenarios. Figure 3.1.4 was generated using the Resources for the Future Global Energy Outlook tool (RFF 2025). The black line shows total global observed CO₂ emissions from compiled by the International Energy Agency (IEA). The solid green line is the emission trajectory developed by BP (British Petroleum??) Energy taking account of current emission control policies and global energy use outlooks. It overlaps a solid black line which represents the emission projection from the IEA also taking account of energy use projections and current policies. The dashed lines show the range of IPCC SSP policies scenarios. As of 2023, global CO₂ emissions have been tracking well below the SSP scenarios especially the two highest ones (SSP5-8.5 and SSP3-7.0).

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Carbon dioxide emissions (Million metric tons), by Outlooks & Scenarios. Filtered by Region: World; Fuel: All; Outlook: 2023 Shell (Sky 2050).

Source: RFF Global Energy Outlook at www.rff.org/geo

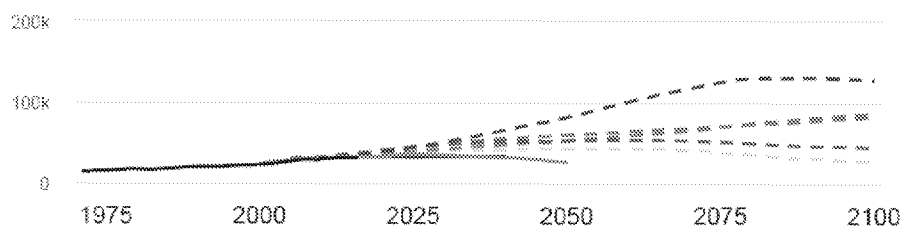


Figure 4.2.1. Observed and projected CO₂ emissions. Source: RFF (2025).

4.2.2 The carbon cycle relating emissions and concentrations

Global carbon cycle models relate concentrations to emissions using estimates of various land and ocean processes that remove CO₂ from, and emit CO₂ into, the atmosphere. Our understanding of these processes was reviewed by Crisp et al. (2021). The natural fluxes of CO₂ in and out of the Earth's surface are very large, many times an order of magnitude larger than anthropogenic emissions, but those CO₂ sources and sinks were assumed to be in approximate balance in pre-industrial times, as evidenced by relatively constant levels of atmospheric CO₂ in centuries past derived from found in air bubbles trapped in ice cores. This is one of several reasons why increasing atmospheric CO₂ levels are believed to be dominated by anthropogenic sources.

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Specifically, fossil fuel burning (and to a lesser extent land use [biomass burning] and cement production) has led to steadily increasing CO₂ levels in the atmosphere, as shown in Fig. 1.2.1. CO₂ emissions from fossil fuel burning is a small fraction of the natural carbon cycle components. About 44,000 Gigatonnes of carbon-equivalent (GtC) are stored in the atmosphere and oceans, mostly in the form of CO₂. (Ciais et al. 2013). Between 150 and 200 GtC are released naturally each year through oceanic outgassing and land-based processes like plant decay and animal respiration. A variable but roughly equivalent amount is absorbed each year by the land and oceans, with a small net loss from the atmosphere because the formation of deep ocean sediment sequesters some carbon permanently. Global fossil fuel consumption and cement manufacture released about 10.3 GtC in 2023, up from 6.2 GtC in 1990 (Ritchie et al.

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2024). Of this, about half is naturally sequestered through plant growth and oceanic uptake while the remainder, about half, adds to the atmospheric stock (Ciais et al. 2013).

As noted, each year natural processes remove a net amount of CO_2 equivalent to about 50% of global emissions. Thus, anthropogenic CO_2 emissions average twice what is required to explain the atmospheric rise in CO_2 concentration. The near-constancy of that 50% fraction (the "airborne fraction") also means that the more CO_2 humanity produces, the faster Nature removes it from the atmosphere. That 50% fraction changes somewhat from year to year due to natural carbon cycle imbalances from El Nino, La Nina, and varying weather patterns. There was also a substantial additional reduction in atmospheric CO_2 after the 1991 eruption of Mt. Pinatubo, a curious result that has yet to be explained (Angert et al, 2004).

The main processes which remove excess CO_2 from the atmosphere are increased production-growth of land vegetation (especially at high latitudes), some increase in the sequestering of carbon in soils, and uptake of CO_2 by the ocean due to the increasing partial pressure of atmospheric CO_2 over that of CO_2 dissolved in the ocean. All twenty land carbon cycle models tracked by the Global Carbon Project (Friedlingstein et al., 2024) show land processes have been removing excess CO_2 at an increasing rate since 1959. This is consistent with a "global greening" phenomenon observed by satellites since monitoring of global greenness began in the 1982. This greening has been traced to CO_2 fertilization and greater drought tolerance of plants exposed to elevated CO_2 levels. While there had been some uncertainty whether a greening trend continued beyond 2000, the most recent research (Chen et al., 2023) has shown continued greening, with even some slight acceleration since 2000. Global greening is discussed further in Section 3.1.

While land vegetation has been responding positively to more atmospheric CO_2 , uptake of extra CO_2 by ocean biological processes remains too uncertain to be reliably measured. Our current understanding of these and many more carbon cycle processes was reviewed by Crisp et al. (2021).

Public policy can only change the rate of emissions, not the concentration in the atmosphere. For criteria air contaminants the rate and concentration are closely connected because the lifetime is short and the concentration is small. When emissions are reduced the local pollution concentration drops rapidly, usually on a time scale of within a few days. Not so with CO_2 . But the global average CO_2 concentration behaves very differently, since global carbon cycle is vast and slow. A change in local emissions today will only have only a very small global effect, and even that only after a long time lag with a long delay. After a pulse (release) of CO_2 emissions to the atmosphere only about 40 percent ($\pm 15\%$) of the extra CO_2 will have been

sequestered after twenty years. After a thousand years about 75 percent ($\pm 10\%$) will have been sequestered, and the remainder will gradually be gradually removed over the ensuing tens of thousands of years (Ciais et al. 2013, pp. 472-473). Consequently, it will take decades or centuries for U.S. CO₂ emission reductions to have a lead meaningful impact on a reduction in the global CO₂ concentration.

To reduce the atmospheric stock of CO₂, assuming the entire increase is anthropogenic, would require emissions to fall below the natural sequestration rate. Since that rate has been averaging about 50% of emissions, a reduction of global emissions by 50% would (at least temporarily) halt the rise in atmospheric CO₂. The 1997 Kyoto Protocol proposed to cap industrial nations' CO₂ emissions at a modest five percent below 1990 levels by the year 2012. Even though this policy ended up being too costly for most nations to implement, full compliance would not have substantially reduced atmospheric CO₂ levels. It would only have slightly slowed CO₂ growth, reaching the projected 2100 level in 2105 instead (Wigley 1998). Similarly, Lomborg (2016) used the widely-used MAGICC climate model and showed that full compliance with the Paris Accord would not stop warming, it would only prevent about 0.1C warming and delay hitting the baseline year 2100 temperature levels by about a decade.

Thus, in contrast with conventional air pollution control, even drastic local actions yield extremely small have minimal local effects, and only after a long time lag with a long delay. The practice of referring to unilateral US reductions as "combating climate change" or "taking action on climate" reflects a profound misunderstanding of the scale of the issue. The scale problem is compounded by recognizing that U.S. motor vehicles account only for about 4 percent of global CO₂ emissions so that even a fifty percent reduction in those emissions would have a vanishingly small effect on the global climate.

~~4.3 Aerosols and the uncertainties associated with them.~~

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~~The role of this chapter should be to address radiative forcing — not ECS or warming attribution. I think that the material in this section should be moved to ECS or attribution. There is huge uncertainty in the aerosol indirect effect, which relates directly to radiative forcing. I can write up something on this~~

~~THIS PARA SHOULD BE DELETED HERE. THIS IS COVERED IN THE ATTRIBUTION CHAPTER and the Climate sensitivity chapter. Climate sensitivity to CO₂ (Equilibrium~~

Climate Sensitivity or ECS) cannot be directly measured in part because it represents the net effect of (at least) two counteracting forces: warming from GHG's and cooling from aerosols. The observed warming can be made to be consistent with a wide range of pairs of these forces. In the following schematic, the warming represented by the red arrow could be due to the High GHG warming/strong aerosol cooling pair, or the Low GHG warming/weak aerosol cooling pair, or something in between.

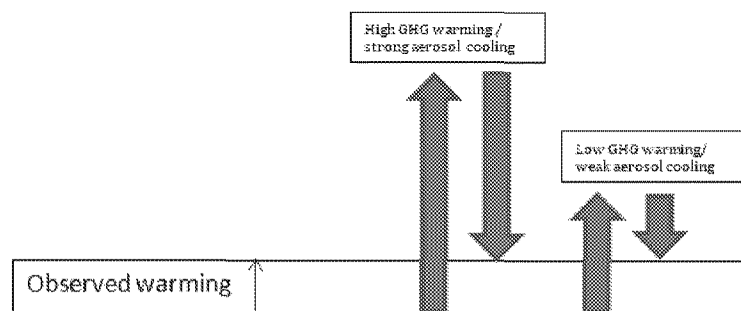


Figure 4.3.1: High and low climate sensitivity to GHGs can be reconciled with the same warming by assuming an offsetting aerosol cooling effect.

~~THIS CAN GO IN ECS CHAPTER~~ Consequently, research on the strength of aerosol cooling is central to forming valid ECS estimates. Lewis and Curry (2018) note that after the IPCC AR5 was published in 2013, eleven studies appeared in the scientific literature all finding that aerosol cooling was weaker than had previously been conjectured. Combining the updated aerosol estimates with greenhouse gas, ocean heat uptake and atmospheric warming data from the IPCC and applying standard empirical methods, Lewis and Curry (2018) estimated the best-guess ECS to be 1.66°C with a 95 percent uncertainty range of 1.15°C–2.7°C. They concluded that based on the ECS values derived from most IPCC climate models were incompatible with observed data.

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~~Evidence of lower aerosol cooling (implying lower ECS) has continued to be found, such as Liu et al. (2021). THIS COULD BE MADE TO BE RELEVANT TO RADIATIVE FORCING CHAPTER~~ Liu and his coauthors tested the hypothesis that aerosols from wildfires has increased since before the 20th century which, if true, would mean there had to have been relatively strong CO₂ warming over that period offsetting the aerosol cooling. They examined soot layers in ice cores extracted from Antarctica and South America and determined that wildfire activity prior to the 20th century was higher than

previously believed. Instead of wildfire activity rising steadily from the 1700s to the present it was high all the way along, which means there was no increase in aerosols over that time—therefore the previously hypothesized aerosol cooling trend in the Southern Hemisphere over the 20th century did not happen. They pointed out how this finding relates to the climate sensitivity issue:

Accurate estimates of aerosol radiative forcing are also crucial for better understanding the transient climate response (TCR) and equilibrium climate sensitivity (ECS) to increasing CO₂ and more accurate projection of future climate change. The negative aerosol radiative forcing can, in part, cancel out the positive forcing of increasing greenhouse gases and contribute to the uncertainty of total radiative forcing. An overly large aerosol cooling implies that models might overestimate TCR and ECS to reproduce historical temperature response. A recent study using one of the latest generation CMIP6 climate models (E3SM) suggested that reducing both the magnitudes of negative aerosol radiative forcing and climate sensitivity yields a better agreement with the observed historical record of the surface temperature.

(Liu et al. 2021)

Liu told the UK Daily Mail²

Climate scientists have known that the most recent generation of climate models have been over-estimating surface temperature sensitivity to greenhouse gases, but we haven't known why or by how much. This research offers a possible explanation.

I really think we should limit direct quotes to IPCC or other official docs, or something that is especially profound.

THIS IS ATTRIBUTION More evidence pointing to weak aerosol cooling was reported by Wang et al. (2021). They noted that the strength of aerosol cooling is partly mediated by cloud behavior and differs between the North and South Hemispheres because of the different density of aerosol emissions. This allowed them to construct another test of climate model validity, which came out in favor of low ECS models. In their words:

Since anthropogenic aerosols primarily concentrate in the Northern Hemisphere, strong aerosol-cloud interaction models produce an interhemispheric asymmetric warming. We show that the observed warming asymmetry during the mid-to-late

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²...Available online at...[HYPERLINK "<https://www.dailymail.co.uk/sciencetech/article-9629919/Climate-change-warming-effect-greenhouse-gases-overestimated-ice-core-study-suggests.html>"]

20th century is more consistent with low ECS (weak aerosol indirect effect) models. PARAPHRASE, DIRECT QUOTE NOT NEEDED

Wang et al. (2021)

~~THIS PARA IS AN ATTRIBUTION STATEMENT, NOT A FORCING STATEMENT. To summarize, measuring the effect of CO₂ warming requires making an assumption about the strength of aerosol cooling. While it is very uncertain a substantial body of recent evidence points to it being relatively weak, which implies CO₂ warming is likewise weak. The literature estimating ECS will be reviewed in Section XX.~~

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Summary

- The global climate is naturally variable. Anthropogenic CO₂ emissions add to that variability by changing the total radiative balance in the atmosphere.
- The IPCC has downplayed the potential role of the sun in climate change but there are Total Solar Irradiance reconstructions that imply it may have played an important role. ~~been important~~, and the modern record is uncertain due to an interruption in satellite coverage.
- ~~When Projections of anthropogenic emissions are combined estimates along with carbon cycle model estimates of atmospheric CO₂ removal are combined we get estimates of future CO₂ concentrations and hence the radiative forcings. These are input to required by climate models to estimate future anthropogenic changes in the temperatures of warming.~~
- IPCC emission scenarios envelopes have tended to exceed observed trends.
- The vast majority of academic climate "impacts" studies in recent years are based upon the extreme RCP8.5 scenario that is considered implausible, and its usage as a business-as-usual scenario is misleading.
- Despite ample evidence that scenario envelopes are exaggerated, and despite criticism of this practice in the peer-reviewed literature, the IPCC's most recent scenario set called (SSP) carries on with perpetuates this pattern of practice.
- The global carbon cycle heavily dampens the effect of changes in local (e.g. U.S.) CO₂ emissions. Even global-scale emission reductions will have only small, much delayed effects, long in the future.
- ~~Measuring Knowing the effect magnitude of CO₂ warming requires making an assumption about knowing the strength of aerosol cooling. While that is very uncertain, a substantial body of recent evidence points to it being relatively weak, which implies implying CO₂ warming is likewise weak. THIS IS AN ATTRIBUTION STATEMENT.~~

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Scaffeta, Nicola, Richard C. Willson, Jae N. Lee and Dong Wu (2019) Modeling Quiet Solar Luminosity Variability from TSI Satellite Measurements and Proxy Models during 1980–2018. *Remote Sensing* 11(21) 2569 [[HYPERLINK "https://doi.org/10.3390/rs11212569"](https://doi.org/10.3390/rs11212569)]

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Wang, C., Soden, B. J., Yang, W., & Vecchi, G. A. (2021). Compensation between cloud feedback and aerosol-cloud interaction in CMIP6 models. *Geophysical Research Letters*, 48, e2020GL091024. [[HYPERLINK "https://doi.org/10.1029/2020GL091024"](https://doi.org/10.1029/2020GL091024)]

Jenkins, S., Smith, C., Allen, M. et al. Tonga eruption increases chance of temporary surface temperature anomaly above 1.5 °C. *Nat. Clim. Chang.* 13, 127–129 (2023). [[HYPERLINK "https://doi.org/10.1038/s41558-022-01568-2"](https://doi.org/10.1038/s41558-022-01568-2)]

Schoeberl, MR., Y. Wang, G. Taha, D.J. Zawada, R. Ueyama and A. Dessler, 2024. Evolution of the climate forcing during the two years after the Hunga Tonga-Hunga Ha'apai eruption. *J. Geophys. Res.*, 129, [[HYPERLINK "https://doi.org/10.1029/2024JD041296"](https://doi.org/10.1029/2024JD041296)]

1 Carbon dioxide as distinct from criteria air contaminants pollutant

This report is chiefly concerned with carbon dioxide (CO₂) emissions from fossil fuel use. In 2007, the Supreme Court ruled that GHGs (CO₂ among them) were "pollutants" subject to regulation under that Clean Air Act. Although it has become common to refer to CO₂ as "pollution" this is a misnomer. In the That framework of United States clean air policy defines there are six types of so-called Criteria Air Contaminants (EPA, undated): particulate matter, ground-level ozone, Sulfur Dioxide, Nitrogen Dioxide, Lead and carbon monoxide (CO). Air contaminants are subject to regulatory control because they cause local problems depending on concentrations that include nuisances (odor, visibility problems), damage to plants and, at high enough exposure levels, toxicological effects in humans.

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"https://www.oyez.org/cases/2006/05-1120"]

While the definition of "pollutant" is ultimately a legal one, there are important scientific distinctions between CO₂ and the Criteria Air Contaminants. The latter are subject to regulatory control because they cause local problems depending on concentrations that include nuisances (odor, visibility problems), damage to plants and, at high enough exposure levels, toxicological effects in humans. has not historically been viewed as an air pollutant in the US or elsewhere because it is. In contrast, CO₂ is odorless, does not affect visibility and has no toxicological effects at ambient levels. It is a naturally-occurring part of the atmosphere and a key component of human and plant respiration. CO₂ is essential for plant photosynthesis and higher levels are generally considered beneficial for vegetation. In these aspects, it is similar to water, as will be discussed in this report.

Commented [SK2]: Whether CO₂ is a pollutant is ultimately a LEGAL question in which we've no particular expertise. There are, however, important scientific aspects to the question where we can credibly opine. I've tried to rewrite to reflect that.

Ambient outdoor air today contains about 420 parts per million (ppm) CO₂, increasing at about 2 ppm per year. The US Occupational Safety and Health Administration issues guidelines for indoor workplaces in which elevated CO₂ may might be encountered, such as where dry ice is used. The Permissible Exposure Limit is 5,000 ppm over 8 hours (OSHA 2024). Allen *et al.* (2015) reported evidence of diminished performance on some cognitive tasks among workers in office cubicles when exposed to CO₂ levels above 1,000-1,500 ppm. These levels are far larger than any plausible value through the end of the 22nd century.

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The growing amount of CO₂ in the atmosphere directly influences the earth system by promoting plant growth (global greening), thereby enhancing agricultural yields, and also by neutralizing ocean alkalinity. But the primary concern about CO₂ is its role as a greenhouse gas (GHG), that alters the earth's energy balance. How the climate will respond to that influence is a complex question that will occupy much of this report.

The main concern about CO₂ is its potential effects on the global climate. This is a very complex question which will occupy much of this report. We will begin in the next section by looking at the role of CO₂ in promoting global greening and agricultural productivity growth, then we will examine the effect of CO₂ on ocean alkalinity. We then turn to CO₂'s role as a so-called greenhouse gas (GHG), beginning with a brief description of radiative forcing, the carbon cycle and the role of aerosols. Part II of this report discusses in detail the topic of the climatic response to GHGs. Part III discusses some aspects of the impacts of climate change on ecosystems and society.

US Environmental Protection Agency (Undated) Criteria Air Pollutants. [HYPERLINK "https://www.epa.gov/criteria-air-pollutants"] accessed April 29 2025.

US Occupational Health and Safety Administration (2024) "OSHA Occupational Chemical Database: Carbon Dioxide" [[HYPERLINK "https://www.osha.gov/chemicaldata/183"](https://www.osha.gov/chemicaldata/183)]

Allen, Joseph G, Piers MacNaughton, Usha Satish, Suresh Santanam, Jose Vallarino and John D.S. Spengler (2015) Associations of Cognitive Function Scores with Carbon Dioxide, Ventilation, and Volatile Organic Compound Exposures in Office Workers: A Controlled Exposure Study of Green and Conventional Office Environments. *Environmental Health Perspectives* 124(6) pp. 805-812 [[HYPERLINK "https://doi.org/10.1289/ehp.1510037"](https://doi.org/10.1289/ehp.1510037)]

8 Extreme weather in the US and elsewhere

8.1 Introduction

Weather extremes, usually related to temperature and/or precipitation, often can disrupt infrastructure and therefore endanger human health and thriveabilitywellbeing. Indeed, the ability of any surface-dwelling species to live productively is somewhat constrained by these extremes which in essence create the bounding limits for survival. The issue is not whether extremes occur, for they are intrinsic to the chaotic climate system. Rather, it is whether there are long-term (decadal scale) changes in the frequency and/or character of extremes ("detection"), as well as the extent to which such changes here is whether these extremes, and their attendant changes in potential dangerhazards, may are be changing and if so whether the change is in response caused by to anthropogenic emissions increases in infrared-absorbing of greenhouse gases (GHGs) ("attribution"; (e.g., IPCC AR6 Seneviratne et al. 2021).

It is naive to assume that any recent unprecedented extreme event observed recently is caused by human influences on the climate. Unfortunately, that's That assumption is wrong in two ways. First, climate is about the statistical properties of weather over decades, not single events. And second, there are only about 130 years of the reliable Unfortunately, observational records that can be analyzed statistically, extend back only for the sample of time from which we are able to quantitatively analyze variations in extreme events is quite brief, about around 130 years. That brief interval does not. This period certainly does not begin to contain all of the extreme events that the climate system is able to can create naturally on its own. Over geologic time the climate system has generated an (essentially) infinite variety of weather patterns and extremes which that humans have never observed, and thus do not enter our are absent from the databases from which used to determine extreme statistics,¹ are determine d [see *Perils of short data records* below]. Thus, assuming that aFor that reason, attributing climate pattern or an extreme event hitherto unprecedented in the record not experienced in our lifetime must therefore be the result of enhanced GHG concentrations requires the assumptions about the smallness magnitude of that natural variations are insignificant.

This is especially true for precipitation events. The hydrological literature has long noted the phenomenon of *Long Term Persistence* (LTP) in rainfall data (Hurst 1951, Cohn and Lins 2005, Markonis and Koutsoyiannis 2015). LTP has a formal mathematical definition but it can be thought of intuitively as the presence of natural variations with strong autocorrelation properties that result in cycle-like behavior on long time scales. The presence of LTP requires very-long data samples records to obtain accurately accurate estimates of variance variability. Analysis of, analysis of data samples that are records short relative to the LTP scale will tend to yield underestimate variability, therefore underestimated variances which in turn yields over stating the significance of apparent trends and underestimation underestimating of the likelihood of extreme events (Cohn and Lins 2005).

A good example of LTP is the eight-century long record of the annual minimum height of the Nile River observed at Roda Island in Cairo shown below in Figure 8.1.1. Since human influences on the global climate were negligible before the 20th century, the century-scale variability of the thirty-year average is entirely natural; Egyptians of the seventh and eight centuries would have been incorrect to assume that the worsening drought during that time was the "new normal."

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¹ For example, under the simplest statistical assumptions there is a 37 percent chance that a 100-year event is NOT present in a century-long record.

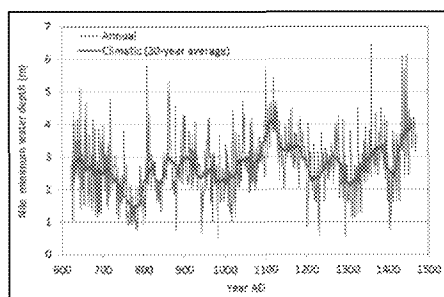


Figure 8.1.1: Nile River discharge [details, source]

With these caveats in mind we examine the evidence for changes in selected weather and climate extremes. A theme that emerges when reviewing this topic is the wide gap between public perceptions and scientific evidence. It has become routine in media discussions, government and private sector discussions and even in some academic literature to make generalized assertions that extreme weather of all types is getting worse due to GHGs and climate change. Yet expert assessments have not typically drawn such sweeping conclusions and instead have emphasized the difficulty both of identifying specific trends and establishing a causal connection with anthropogenic forcing.

In the sections to follow we cite provide excerpts from various IPCC and NCA assessment reports denoting the sources as follows:

For the benefit of readers who may not have read the relevant reports in the Appendix to this chapter we will begin provide with extended excerpts of these findings from previous IPCC and NCA assessments, then in the remainder of this chapter survey additional data relevant to US and global extreme weather trends.

8.2 Review of IPCC and NCA Findings on Extreme Weather

The sources we review will be denoted as follows:

SREX: The IPCC *Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* (2012)

AR5: The IPCC *Fifth Assessment Report Working Group 1* (2013).

AR6: The IPCC *Sixth Assessment Report Working Group 1* (2021).

NCA17: The US *Climate Science Special Report of the Fourth National Climate Assessment* (2017) Volume I Chapter 6.

Note that in the excerpts provided *italics* are in the original whereas **boldface** emphasis is added.

8.2.1 Overview Context: IPCC Assessment of signal emergence in extreme weather types (AR6 WG1 Table 12.12)

This chapter is concerned with detection of trends. Chapter 7 looked at attribution including for extreme weather. Since there is considerable public interest in the question of whether humans are causing trends in extreme weather to get worse it is useful to begin with the summary Table 8.2.1 which reproduces the findings of AR6 Table 12.12 which indicates, for 34 major weather event and impact types, whether a signal of anthropogenic forcing has been detected in the historical record (column 1), whether such a signal is likely to emerge by 2050 under the extreme RCP8.5 scenario (column 2) and whether it is likely to emerge by 2100 under RCP8.5 forcing (column 3). It should be borne in mind that the latter two columns suffer from the deficiencies of GCMs discussed in Chapter XX. And as we discussed in Ch X7 on attribution, AR6 offers conflicting messages about attribution of extreme weather. Nevertheless, we provide this Table for reference context.

Several patterns stand out. First, detection of an anthropogenic signal is asserted with *high confidence* in only four of the 34 weather impact categories, and with *medium confidence* in a further four. The IPCC does NOT claim to have detected an anthropogenic signal in the remaining 26 categories. Of the four *high confidence* assertions, two are for changes in average temperatures (air and ocean), which are not measures of extreme weather. Further, two of the four *medium confidence* assertions are related to ocean chemistry and are also not related to extreme weather. The IPCC does NOT assert a detectable human influence on many non-temperature weather features such as wind, precipitation, flooding, and drought.

Second, columns 2 and 3 show that the IPCC expects very few anthropogenic trends to emerge within this century, even under the most extreme forcing scenario. As we discuss in Section 4.2 the RCP8.5 scenario is an implausible high-end storyline, not a “base case” or “business-as-usual” projection. Even so, most weather impacts are not expected to show an anthropogenic signal this century. Natural variability dominates patterns of extreme weather systems and simplistic assertions of trend detection are frequently undermined by regional heterogeneity and trend reversals over time.

Climate Impact Driver Type	Climate Impact Driver Category	Already Emerged in the Historical Record?	Emerging by 2050 in Most Extreme CO2 Emissions Scenario?	Emerging by 2100 in Most Extreme CO2 Emissions Scenario?
Heat & Cold	Average air temperature	YES in most regions	YES	YES
	More heat extremes	YES in most regions	YES in land regions	YES
	Fewer cold extremes	YES in a few regions	YES in many regions	YES
	Less frost	NO	NO	NO
Wet & Dry	Average Precip. (Increase or Decrease)	NO	YES (incr) YES (decr)	YES (incr) YES (decr)
	River flooding	NO	NO	NO
	Heavy precip & pluvial flood	NO	NO	YES in a few regions
	Landslide	NO	NO	NO
	Aridity	NO	NO	NO
	Hydrologic Drought	NO	NO	NO
	Agricultural & ecological drought	NO	NO	NO
	Fire weather	NO	NO	NO
Wind	Average wind speed	NO	NO	NO
	Severe wind storm	NO	NO	NO
	Tropical cyclone	NO	NO	NO
	Sand and dust storm	NO	NO	NO
Snow and Ice	Snow, glacier & ice sheet	NO	YES in a few regions	YES Arctic snow
	Permafrost	YES	YES	YES
	Lake & river ice	NO	YES	YES

	Arctic sea ice	YES	YES	YES
	Antarctic sea ice	NO	YES	YES
	Heavy snowfall and ice storm	NO	NO	NO
	Hail	NO	NO	NO
	Snow avalanche	NO	NO	NO
Coastal	Relative sea level	NO	YES	YES
	Coastal flood	NO	NO	NO
	Coastal erosion	NO	NO	NO
	Average ocean temperature	YES	YES	YES
Open Ocean	Marine heat wave	NO	NO	NO
	Ocean acidity	NO	YES	YES
	Ocean salinity	YES	YES	YES
	Dissolved oxygen	YES (Pacific & S. Ocean)	YES	YES
Other	Air pollution weather	NO	NO	NO
	Solar or IR radiation at surface	NO	NO	NO

Table 8.2.1. IPCC AR6 summary of the probable emergence of an anthropogenic signal above natural climate variability for all global or regional "climate impact drivers" (CIDs) of concern for humans and ecosystems in response to increasing atmospheric greenhouse gas concentrations (primarily CO₂). Source: Table adapted from report of Working Group I, Table 12.12). Red = high confidence; yellow = medium confidence; green = no anthropogenic signal detectable above natural variability (50% confidence).

Taking wind as an example, the IPCC claims that an anthropogenic signal has NOT emerged in average wind speeds, severe windstorms, tropical cyclones, or sand and dust storms, and none are expected to emerge this century even under an extreme emissions scenario. The same applies to drought and fire weather. This table alone suffices to illustrate the gap between IPCC expert assessments of extreme weather and discussions in the popular media and political arenas. As we show below the Table reflects longstanding conclusions of the IPCC and other assessment bodies. In the next few sections we will simply present without comment excerpts from past assessment reports.² In selecting these excerpts, we've focused on the highest-level summaries to avoid accusations of bias through "cherry picking".

²In these excerpts we have added **bold-face** emphasis, while *italicized* emphasis on confidence terms appears in the original sources. Citations in quoted text can be found in the underlying reports but are not reproduced here.

8.2.73 Hurricanes and Tropical Cyclones

The AR6 assessed this topic as follows.

AR6: There is *low confidence* in most reported long-term (multidecadal to centennial) trends in TC frequency or intensity-based metrics due to changes in the technology used to collect the best-track data. (Chapter 11, p. 1585)

AR6: It is *likely* that the global proportion of major (Category 3–5) tropical cyclone occurrence has increased over the last four decades. . . . There is *low confidence* in long-term (multidecadal to centennial) trends in the frequency of all-category tropical cyclones. (SPM A.3.4)

AR6: A subset of the best-track data corresponding to hurricanes that have directly impacted the United States since 1900 is considered to be reliable, and shows **no trend in the frequency of U.S. landfall events**. (Chapter 11 Summary, p. 1585)

Hurricane strength records for the North Atlantic and the Western Pacific go back to 1950 and the record does not show an increase in either total or major TCs. Figure 8.3.1 was published by Roger Pielke Jr. as an update to the Best Track data series originally presented in Weinkle et al. (2012).

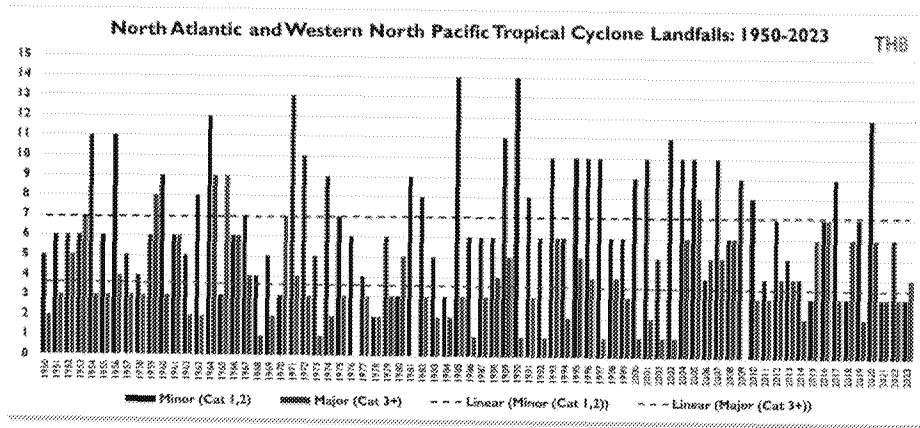


Figure 8.3.1. Tropical Cyclone Landfalls. Source: [HYPERLINK "<https://rogerpielkejr.substack.com/p/global-tropical-cyclones>"], Weinkle et al. (2012)

Similarly, Figure 8.3.2 (Maue 2025, [HYPERLINK "<https://climatlas.com/tropical/>"]) shows that both all hurricanes and major hurricanes have not become more common since 1980, the period of rapidly growing human influences. In fact, both numbers have trended down slightly since the 1990s:

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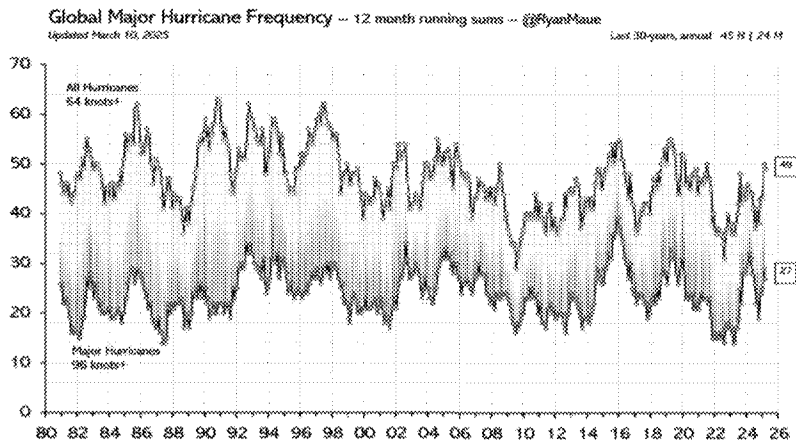


Figure 8.3.2: Global hurricane frequency. Source: Maue (2025)

A metric that combines the number, duration, and strength of TCs is the Accumulated Cyclone Energy (ACE) Index maintained at Colorado State University, shown in Figure 8.3.3. It clearly shows no long-term increase, in fact declining slightly since 1990.

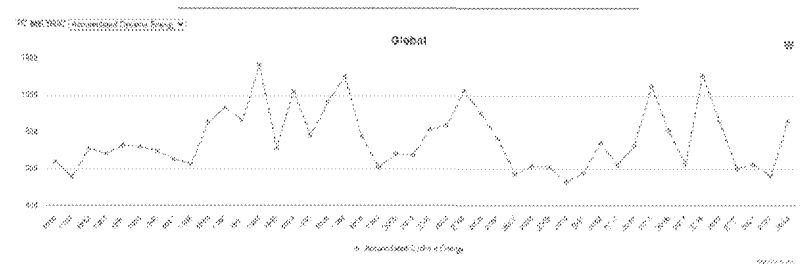


Figure 8.3.3: Global Accumulated Cyclone Energy. Source: Klotzbach (2025)

[HYPERLINK "<https://tropical.atmos.colostate.edu/Realtime/index.php?arch&loc=global>"]

Note that Tu et al. (2024) report that the Power Dissipation Index (PDI), another different measure that combines hurricane number, duration, and strength, has either remained unchanged or has declined in all global oceanic basins since the mid-1990s.

Today's global climate simulations are too coarse to project changes in TCs directly. Rather, projections are derived from finer "downscaled" simulations or proxies involving sea surface temperatures, winds, and aerosols. By those methods, a warming climate is expected to show declining hurricane formation rates. (Chand et al. 2022). Climate models also project fewer Tropical Cyclones under future global warming, and even though models project they will increase in strength, the annual averages of rainfall maxima decline (Stansfield et al. 2020).

8.3 Tornadoes SREX (p. 159):

There have been no significant trends observed in global tropical cyclone frequency records, including over the present 40-year period of satellite observations (e.g., Webster et al., 2005). Regional trends in tropical cyclone frequency have been identified in the North Atlantic, but the fidelity of these trends is debated (Holland and Webster, 2002; Landsea, 2007; Mann et al., 2007a). Different methods for estimating undercounts in the earlier part of the North Atlantic tropical cyclone record provide mixed conclusions (Chang and Guo, 2007; Mann et al., 2007b; Kunkel et al., 2008; Vecchi and Knutson, 2008). Regional trends have not been detected in other oceans (Chan and Xu, 2009; Kubota and Chan, 2009; Callaghan and Power, 2011). It thus remains uncertain whether any observed increases in tropical cyclone frequency on time scales longer than about 40 years are robust after accounting for past changes in observing capabilities (Knutson et al., 2010).

AR5 (pp. 216-17):

Current data sets indicate no significant observed trends in global tropical cyclone frequency over the past century and it remains uncertain whether any reported long-term increases in tropical cyclone frequency are robust after accounting for past changes in observing capabilities (Knutson et al., 2010). No robust trends in annual numbers of tropical storms, hurricanes and major hurricanes counts have been identified over the past 100 years in the North Atlantic basin. Measures of land-falling tropical cyclone frequency (Figure 2.34) are generally considered to be more reliable than counts of all storms which tend to be strongly influenced by those that are weak and/or short lived. Callaghan and Power (2011) find a statistically significant decrease in Eastern Australia land-falling tropical cyclones since the late 19th century although including 2010/2011 season data this trend becomes non-significant (i.e., a trend of zero lies just inside the 90% confidence interval). Significant trends are not found in other oceans on shorter time scales (Chan and Xu, 2009; Kubota and Chan, 2009; Mohapatra et al., 2011; Weinkle et al., 2012), although Grinstead et al. (2012) find a significant positive trend in eastern USA using tide gauge data from 1923–2008 as a proxy for storm surges associated with land-falling hurricanes. Differences between tropical cyclone studies highlight the challenges that still lie ahead in assessing long-term trends.

In summary, this assessment does not revise the SREX conclusion of *low confidence* that any reported long-term (centennial) increases in tropical cyclone activity are robust after accounting for past changes in observing capabilities. More recent assessments indicate that it is *unlikely* that annual numbers of tropical storms, hurricanes and major hurricanes counts have increased over the past 100 years in the North Atlantic basin. Evidence, however, is for a virtually certain increase in the frequency and intensity of the strongest tropical cyclones since the 1970s in that region.

AR6 (p. 1585)

There is *low confidence* in most reported long-term (multidecadal to centennial) trends in TC frequency or intensity-based metrics due to changes in the technology used to collect the best-track data. This should not be interpreted as implying that no physical (real) trends exist, but rather as indicating that either the quality or the temporal

length of the data is not adequate to provide robust trend detection statements, particularly in the presence of multidecadal variability.

There are previous and ongoing efforts to homogenize the best-track data (Elsner et al., 2008; Kossin et al., 2013, 2020; Choy et al., 2015; Landsea, 2015; Emanuel et al., 2018) and there is substantial literature that finds positive trends in intensity-related metrics in the best-track during the "satellite period", which is generally limited to the past ~40 years (Kang and Elsner, 2012; Kishitawal et al., 2012; Kossin et al., 2013, 2020; Mei and Xie, 2016; Zhao et al., 2018; Tauleale and Tsuboki, 2019). When best-track trends are tested using homogenized data, the intensity trends generally remain positive, but are smaller in amplitude (Kossin et al., 2013; Holland and Brayera, 2014). Kossin et al. (2020) extended the homogenized TC intensity record to the period 1979–2017 and identified significant global increases in major TC exceedance probability of about 6% per decade.² In addition to trends in TC intensity, there is evidence that TC intensification rates and the frequency of rapid intensification events have increased within the satellite era (Kishitawal et al., 2012; Balaguru et al., 2018; Bhatia et al., 2018). The increase in intensification rates is found in the best-track as well as the homogenized intensity data.

A subset of the best-track data corresponding to hurricanes that have directly impacted the United States since 1900 is considered to be reliable, and shows no trend in the frequency of U.S. landfall events (Knutson et al., 2019).

AR6: [O]bservational trends in tornadoes, hail, and lightning associated with severe convective storms are **not robustly detected** due to insufficient coverage of the long-term observations. There is *medium confidence* that the mean annual number of tornadoes in the USA has remained relatively constant. (Chapter 11, section 11.7.3, p. 1594)

As noted there is no evidence of trends in US tornadoes or extreme convective storms. Extreme precipitation will be discussed further below.

8.34 Temperature extremes

The AR6 assessment focused on the period after 1950 and reported increasing trends in heat wave frequency and intensity. The NCA17 however noted that heat wave activity in the US reached a peak in the 1930s.

²The underlined text referenced a study (Kossin et al. 2020) that later retracted a portion of its findings. Those authors assembled a data set on global TC incidence spanning 1979 to 2017 from which they claimed that the global fraction of TCs reaching major status (Cat 3–5) rose from 27% during 1979–1997 to 31% during 1998–2017 and that the increase was statistically significant. However, closer examination of their results showed a significant increase only in the North Atlantic (18% to 34%) whereas changes in all other basins (Eastern Pacific, Western Pacific, North Indian, South Indian, South Pacific) were not statistically significant. In a subsequent correction ([HYPERLINK "<https://www.pnas.org/doi/10.1073/pnas.2021573117>"]), Kossin et al. stated that the global probability of observing a major TC rose from 34% during 1979–1997 to 37% in the later period and that the evidence for statistical significance was now weaker. Nevertheless, the authors claimed that the correction did not affect their conclusions.

AR6: “It is *virtually certain* that hot extremes (including heatwaves) have become **more frequent** and **more intense** across most land regions since the 1950s, while cold extremes (including cold waves) have become less frequent and less severe” (SPM, A3.1)

AR6: “In North America, there is very robust evidence for a *very likely* increase in the intensity and frequency of hot extremes and decrease in the intensity and frequency of cold extremes for the whole continent, though there are substantial spatial and seasonal variations in the trends. Minimum temperatures display warming consistently across the continent, while there are more contrasting trends in the annual maximum daily temperatures in parts of the USA.” (Chapter 11, p 1550)

NCA17: “Changes in warm extremes are more nuanced than changes in cold extremes. For instance, the warmest daily temperature of the year **increased** in some parts of the West over the past century, but there were **decreases** in almost all locations east of the Rocky Mountains. In fact, all eastern regions experienced a net **decrease**, most notably the Midwest (about 2.2°F [1.2°C]) and the Southeast (roughly 1.5°F [0.8°C]).” (pp. 190-191)

NCA17: “Since the mid-1960s, there has been only a very slight increase in the warmest daily temperature of the year (amidst large interannual variability). Heat waves (6-day periods with a maximum temperature above the 90th percentile for 1961–1990) increased in frequency until the mid-1930s, became considerably less common through the mid-1960s, and increased in frequency again thereafter. As with warm daily temperatures, heat wave magnitude reached a **maximum in the 1930s**.” (pp. 190-191)

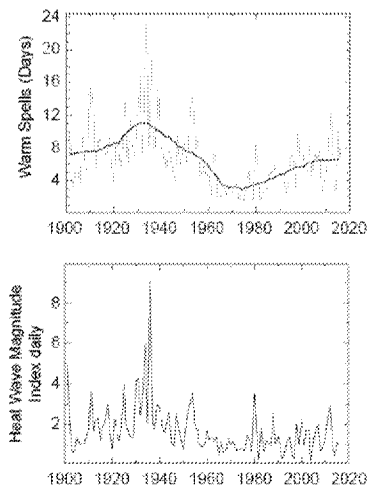


Figure 8.34.1: US Heat waves since 1900. Source: NCA17 Figure 6.4

8.34.1 Temperatures in the US are becoming less extreme

Daily maximum temperatures in the warm season (TMax, May-Sep) and daily minimum temperatures in the cold season (TMin, Dec-Mar) are available beginning in Dec 1898 (126 years). The dataset consists of 1,211 CONUS stations designated as United States Historical Climate Network

or USHCN stations (see Figure 8.34.42; Quinlan et al. 1987, Karl et al. 1990). These stations were selected by NOAA as having the fewest problematic issues with gaps, station moves and instrument changes. Where gaps still exist, nearby stations (bias-corrected) were merged so that the median volume of data available for a station is 98%. Although there are certainly errors in the dataset, with over 1,000 stations we can have relatively high confidence in any underlying signal that might be discovered.

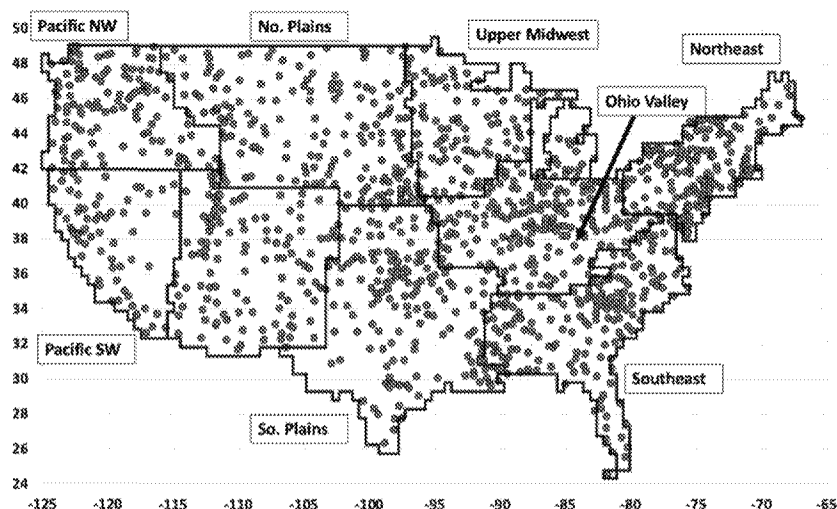


Figure 8.34.42 Locations of USHCN temperature stations. Source: USHCN.

We begin with the question of whether the occurrence of daily record high or low temperatures changed has changed since Dec. 1898. Each warm-season has 153 days (1 May to 30 Sep) and each cold-season has 122 days (1 Dec to 31 Mar). For each station and day, we calculated the year in which the record highest (lowest) temperature occurred. With 126 years of observations, if there were no temperature trends over time, the expected number of records for TMax would be 1.21 ($=153/126$) per station per year and for TMin 0.96 ($=122/126$) per station per year. Figure 8.4.43.3 indicates the observed distribution in time of the occurrence of these extreme events.

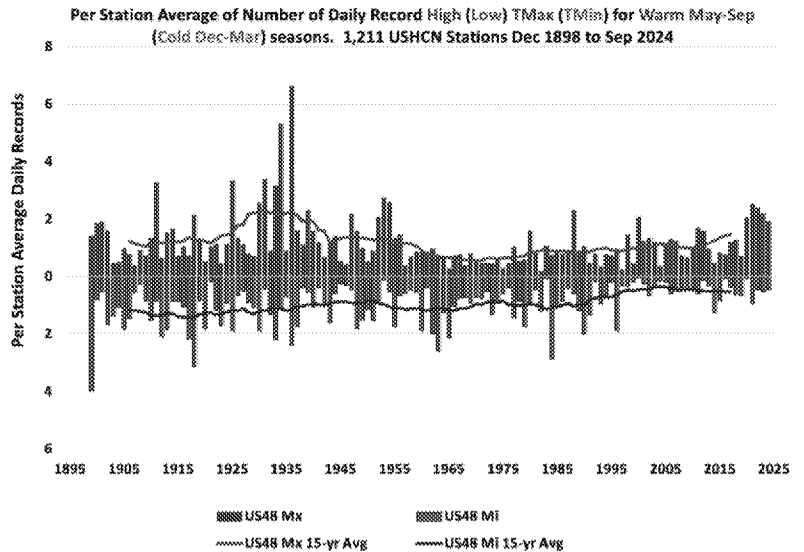


Figure 8.34.23 Number of daily record High (red) and Low (blue) for warm and cold seasons in the CONUS. The lines represent the 15-year running, centered average. Source: 1,211 USHCN stations supplemented as needed to achieve a minimum of 92% of observations in the 126-year period since Dec 1898.

The results indicate a common feature in many metrics of warm-season extremes in the CONUS - the exceptional heat of the 1920s and especially the 1930s, peaking in 1936. On a per-station average, 60% of the TMax records and 59% of the TMin records occurred in the first half of the period (1899-1961).

On the cold side, the Valentine's Day Arctic outbreak in Feb 1899 stands as the most extensive cold extreme experienced by the CONUS, with 1917 2nd. The frequency of cold records has declined, especially over the last quarter of the period in which only 13% of the extreme cold events were measured. In contrast, 25% of the extreme TMax records were achieved in the last quarter in accordance with statistical expectations. These general features have been noted in past assessments (IPCC AR5, IPCC AR6, NCA4, NCA5). Combining the two records the overall reduction in numbers of both cold and hot extremes over the past century indicates a climate less prone to extremes.

This pattern is also shown in Figure 8.34.343. For each station and for each year the hottest warm season and coldest cold-season temperatures were calculated and converted to anomalies relative to the station's long term warm and cold season (respectively) averages. Then the differences between these were computed by station and geographically-averaged over all stations, thus yielding an annual measure of the expected range of local extreme temperatures for each year. Figure 8.4.444 shows the 15-year trailing average of this measure which has clearly declined over the past century.

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**Yearly difference between hottest day in summer and coldest night in winter
Conterminous US, 15-year trailing average**

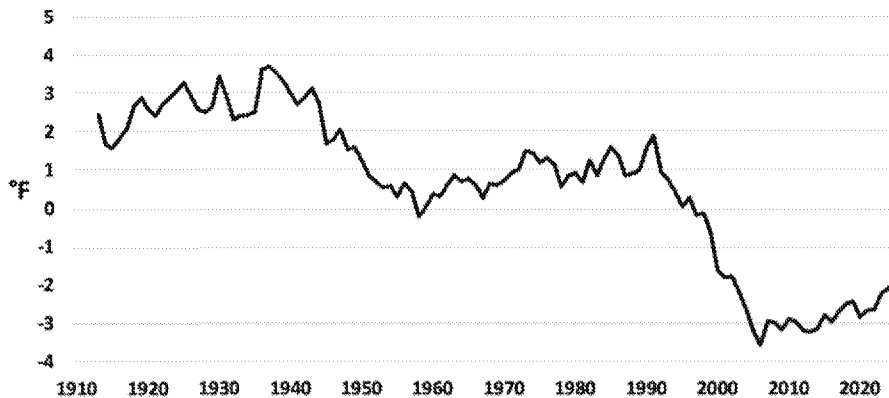


Figure 8.34.34. 15-year trailing average of the difference each year of each station's hottest warm-season TMax and coldest cold-season TMin relative to the long-term average. Source: USHCN, author calculations.

The average difference for each station between the hottest summer TMax and coldest winter TMin has declined about 5°F in the past 126 years. The decline is due mostly to warming winter TMin, but a decline in the magnitude of summer TMax is also a factor. The rise in TMin has been strongly related to the growing presence of manufactured surfaces around the weather stations over the last 100+ years (Spencer et al. 2025).

Summarizing Figures 8.4.4.2.3 and 8.4.2.3.4.4 while temperature extremes are regularly experienced in the US and attract a great deal of media attention, long term records show the US climate has become less extreme over time (milder) when measured in terms of the range between warm season maxima and cold season minima.

8.4.4.2 Exceedances of a heat threshold

Under the heading of "The Risk of Temperature Extremes is Changing", the most recent US National Climate Assessment report (NCA5) notes the increase in a threshold metric of number of days at or above 95°F, stating,

"The western US has been particularly affected by extreme heat since the 1980s ... experiencing a larger increase in days over 95°F, as would be expected given the greater warming in that region relative to the eastern US. Several major heatwaves have affected the US since 2018, including a record-shattering event in the Pacific Northwest in 2021."

Are the occurrences of 95°F days changing? In a climate as varied as that of CONUS, threshold statistics can be misleading. A region with many stations that have near 95°F TMax average temperatures in the summer might see large swings in the metric when only small changes in average temperature occur. Elsewhere with stations that either rarely or virtually always achieve 95°F TMax temperatures, a small change will not impact the results much at all. In the past 126 years, the average CONUS station experienced 129 days exceeding 95°C per 6-yr period, but the regional values range from 278 in the Southern Plains to 9 in the Northeast. Thus, one needs to view such threshold analyses with caution.

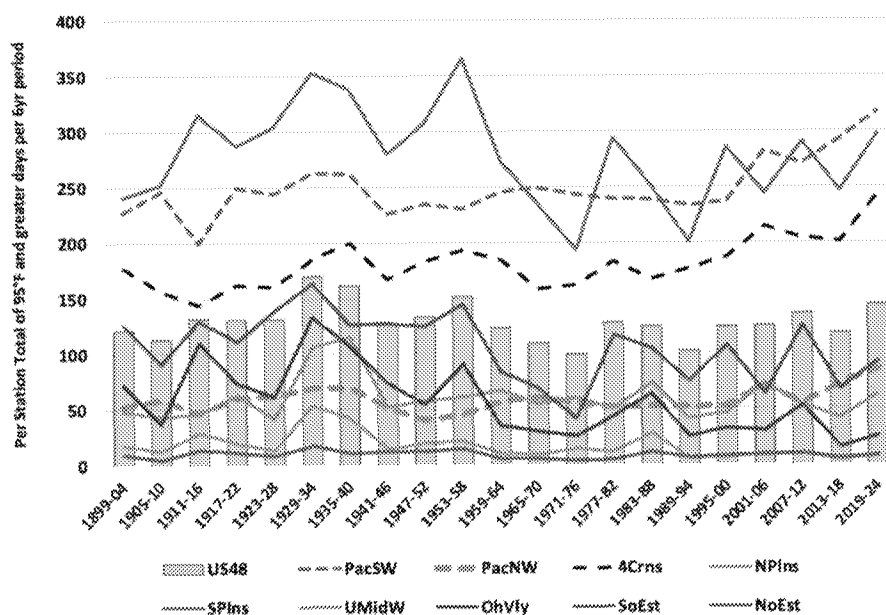


Figure 8.4.334.45. Total number of days $\geq 95^{\circ}\text{F}$ in 6-yr periods, US 48 (bars) and regions (lines). Source: USHCN, author calculations.

In Fig. 8.4.334.45 we see that only three of the nine regions, all in the West, have experienced upward trends in the number of 95°F or hotter days (dashed lines). The CONUS as a whole has not and the other six regions have experienced declines.

The Pacific NW heatwave of 2021 is referenced as of the NCA5 claim, an event we examine more closely in Section 6.4. The evidence indicates it was a "black swan" event; i.e., a single, unprecedented event in the record, not part of a pattern of increasing extreme heat. For example, the 5-day average tropospheric grid-point temperature anomaly over the Pacific NW during that event was $+10.8^{\circ}\text{C}$, the

most extreme NH grid point summer anomaly in the 46 years from over 4 million grids. In contrast, the global anomaly during that time was virtually zero (+0.03 C, Mass et al. 2024).

The heading "The Risk of Temperature Extremes is Changing" suggests positive trends are now being observed in threshold temperatures on a widespread basis, but that is not evidenced in the combined CONUS results of the figures above.

8.4.334.3 Heatwaves

Heatwaves (consecutive days that exceed an extreme threshold) have a greater societal impact than a single daily record. We measure "Heatwave Days" here as the count of all days in May-Sep each year that exceed the 90th percentile and that lie within a run of at least six consecutive days. This is equivalent to the method used in NCA5 except that the reference period here is the entire record 1899-2024 while NCA5 truncated the reference period to 1961-1990, a cool time. That truncation boosts positive results (days exceeding the 90th percentile) in periods warmer than the reference period, especially starting in 1960 and moving to the present (see *Urban Influences* below).

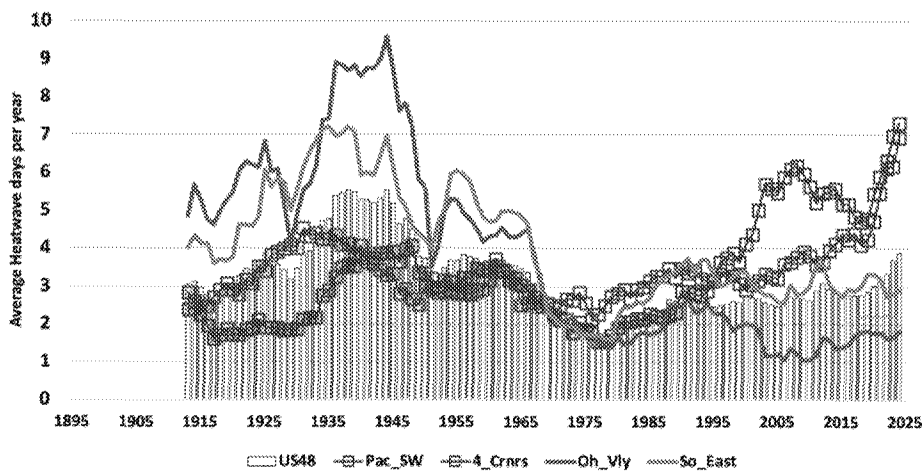


Figure 8.4.434.56 15-year trailing average of number of heatwave days per year per station in the CONUS (bars) and four regions: Pac SW (purple squares, CA, NV), 4_Crnrs (red squares, AZ, NM, UT, CO), Oh Vly (blue, MO, IL, KY, TN, IN, OH, WV) and So East (green, MS, AL, GA, FL, SC, NC, VA).

Figure 8.4.434.56 indicates again the excessive heat of the first half of the 20th century, primarily in the eastern two-thirds of the nation, as seen in the regional values for the Ohio Valley and the Southeast as examples. The West has seen a recent increase of heatwave days and the two regions with the highest number are shown, the Pacific Southwest and the Four-Corners (NCA5). This indicates that the background warm season circulation favored heatwaves in the eastern portions of the country in the first half of the 20th century, but in the 21st century the patterns have favored

heatwaves in the West. For CONUS as a whole, heatwaves are no more common today than they were a century ago.

Of interest here is the regional variation of this metric. The four northern regions (Pacific NW, Northern Plains, Upper Midwest, and Northeast) on average experience 15 to 27 heatwave days per 15-year period. In contrast, the five southern regions (Pacific Southwest, 4-Corners, Southern Plains, Ohio Valley and Southeast) see 37 to 54 such days, essentially twice as many. This suggests the summer circulation pattern is more prone to stationary events in the southern regions while transient systems in the northern regions are more common and thus cut short these potentially longer events.

8.3.4.4 Urban influences

The NCA5 directs readers to the website [HYPERLINK "https://www.globalchange.gov/indicators/heat-waves"] (USGCRP 2023) to view the number of urban heatwaves by decade from the 1960s. The figure shows a monotonic increase in each decade from 2 occurrences per year in the 1960s to 6 in the 2020s. The definition of a heatwave is an unusual but practical measure of human discomfort - a period of at least 2 consecutive days when the minimum apparent temperature (combination of temperature and humidity) exceeds the 85th percentile. Note too, the dataset is limited to the 50 largest U.S. cities.

These increasing values since 1960 presented in USGCRP (2023) are entirely reasonable, but are unrelated to GHG emissions for at least two reasons. Urbanization in these cities is a major factor in the rise of TMin relative to co-located TMax and relative to TMin at rural stations. Also, the 1960s was the coldest decade and 1970s the second coldest decade since the 1910's, so this starting date preconditions the time series to show increases. This does not dismiss the real rise in nighttime temperatures in major U. S. cities and the societal impacts associated with these changes. However, we note for a variety of reasons, that summer TMax (especially in rural areas) serves as better response variable for detecting potential changes in heatwaves influenced by changes in the background climate due, for example, to increasing GHGs (Christy et al. 2009). For the CONUS as a whole, the evidence in this section suggests GHG emissions have had little-to-no effect on heatwaves.

8.4 Tornadoes

AR6: [O]bservational trends in tornadoes, hail, and lightning associated with severe convective storms are **not robustly detected** due to insufficient coverage of the long-term observations. There is *medium confidence* that the mean annual number of tornadoes in the USA has remained relatively constant. (Chapter 11, section 11.7.3, p. 1594)

As noted there is no evidence of trends in US tornadoes or extreme convective storms. Extreme precipitation will be discussed below.

8.4.5.5 Extreme precipitation

The IPCC AR6 assessed that an increase in heavy precipitation has been observed in data starting in the 1950s.

AR6: "The frequency and intensity of heavy precipitation events have **increased** since the 1950s over most land area for which observational data are sufficient for trend analysis (high confidence)." (SPM A3.2)

AR6: "In North America, there is robust evidence that the magnitude and intensity of extreme precipitation has *very likely* increased since the 1950s. Both [one-day maximal] and [5-day maxima] have significantly increased in North America during 1950-2018 "(Chapter 11, p. 1560)

However other data sources indicate less evidence of increasing extreme precipitation when examined over a longer time scale.

Figure 8.4.5.1 shows that US long term data from NOAA shows an insignificantly increasing tendency toward extreme wetness (+0.001% per year)

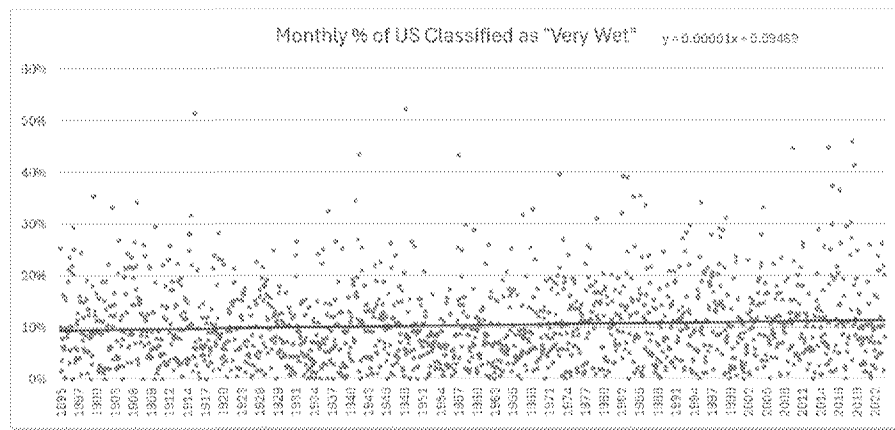
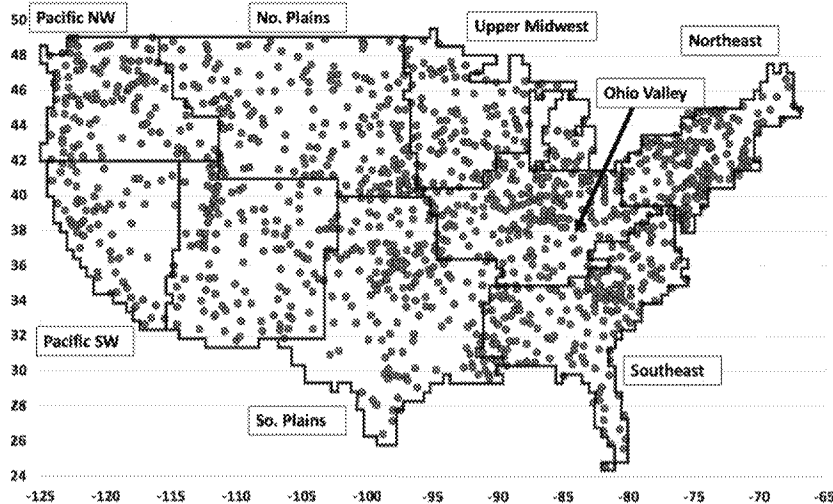


Figure 8.4.5.1: Long term US wetness (%). Source: NOAA [HYPERLINK "<https://www.ncei.noaa.gov/access/monitoring/uspa/wet-dry/0/>"]

Because precipitation involves a discrete phase change (water vapor to liquid), it is stochastic and episodic in character and requires careful statistical treatment to understand variability over long time periods (see 8.1 Introduction). The US National Climate Assessments (NCA4, NCA5) have highlighted an increase in the occurrence of the heaviest precipitation events (defined in different ways) primarily in the eastern half of the CONUS, especially the Northeast, when starting in either 1901 or 1958. Interestingly, the regional variations indicate that the largest increases in extreme events are in the Northeast and the smallest in the West, a trend counter to the changes in temperature extremes.

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McKittrick and Christy (2019) examined long-term and consistent station observations of daily precipitation to test some of these NCA claims for the Southeast and West Coast. When the time series were extended back in time (as far as 1872 in some cases) or when starting later (1978), there were no significant trends for either region.

For this report we updated these findings with similarly constructed observations from 29 stations on the Pacific Coast (1893ff from San Diego CA to Blaine WA) and -24 stations in the humid Southeast (1872ff from Austin TX to Washington DC), and also adding 21 stations in the Northeast (1888ff from Buffalo NY to Gardiner ME). The results of applying the analysis of McKittrick and Christy (2019) were as follows.

[will generate map of stations -RM]

Pacific region:

- Average precipitation trend is significant (downwards) in Astoria, insignificant elsewhere.
- The trend in rainfall variance is positive and significant in Big Sur, insignificant elsewhere.
- The trend in daily maximum precipitation is positive and significant in Aberdeen and Big Sur and negative and significant in Newport (insignificant elsewhere).
- Averaged over all stations in the region none of these three trend parameters is statistically significant.

Southeast region:

- The trend in average precipitation is positive and significant in Mobile and Quitman, insignificant elsewhere.
- The trend in rainfall variance is positive and significant in Mobile, insignificant elsewhere.
- The trend in daily maximum precipitation is positive and significant in Vicksburg and Norfolk, insignificant elsewhere.
- Averaged over all stations in the region none of these three trend parameters is statistically significant.

Northeast region:

- The trend in average precipitation is positive and significant in 9 of 21 locations and in the region averaged overall.
- The trend in rainfall variance is positive and significant in Portland, Albany and Buffalo, insignificant elsewhere.
- The trend in daily maximum precipitation is positive and significant in Portland and Gardiner, insignificant elsewhere.
- Averaged over all stations in the region the trend parameters for variance and maximum precipitation are not statistically significant.

Pacific Coast heavy rainfall events

The Pacific Coast receives considerable precipitation from Atmospheric River (AR) events which often last more than a day or two (e.g., Gershunov et al. 2017, Pan et al. 2024). The worst-known such event in recent history was the ArkStorm that occurred between December 1861 and January 1862, which dumped nearly 10 feet of rain in parts of California and submerged the entire Central Valley for weeks under as much as 15 feet of water (Brewer 1930, Null and Hulbert 2007). Paleoclimate research has found six megastorms more severe than 1861–1862 in California during the last 1800 years, occurring at intervals of 300 years or so (Porter et al. 2011).

SIDEBAR: Perils of short data records

San Francisco provides a good case study of the limitation of using short historical samples to characterize natural variability of extreme events. Suppose we use a 130-year sample of daily San Francisco precipitation from 1895 to 2024 and we look for 3-day, 5-day, 14-day and 30-day rainfall records. The results are as shown in Table 8.2.

<u>Event</u>	<u>Record (inches)</u>	<u>Year</u>
<u>3-day</u>	<u>6.94</u>	<u>2023</u>
<u>5-day</u>	<u>8.55</u>	<u>2023</u>
<u>14-day</u>	<u>12.62</u>	<u>2023</u>
<u>30-day</u>	<u>18.93</u>	<u>1998</u>

Table 8.2: Extreme rainfall records, San Francisco, 1895–2024.

The records all cluster in the more recent data. 2023 appears to be an exceptional year and since it is near the end of the sample it might suggest that the climate has shifted into a more hazardous state, perhaps as a result of human influences.

But the picture is very different if we use a sample that begins 45 years earlier, in 1850. Table 8.3 shows that the record-setting events then all happened in the 1860s. Furthermore 2023 is now not even in 2nd place but falls to 3rd or 4th. Also, comparing the records of the two charts the extreme precipitation events in 1862 and 1867 involved considerably more rainfall than the 1998 and 2023 events, with 14- and 30-day totals about 50 percent higher.

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<u>Event</u>	<u>Record (inches)</u>	<u>Year</u>	<u>Rank of 130-yr extreme</u>
<u>3-day</u>	<u>8.85</u>	<u>1867</u>	<u>3</u>
<u>5-day</u>	<u>9.80</u>	<u>1867</u>	<u>3</u>
<u>14-day</u>	<u>19.05</u>	<u>1862</u>	<u>4</u>

30-day	28.25	1862	2
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Table 8.3: Extreme rainfall records, San Francisco, 1850-2024.

The range of natural variability is made even more remarkable when paleoclimate evidence is examined. Porter et al. (2011) discovered that in the past 1,800 years at least six megastorms were more intense than the devastating 1861-62 ArkStorm that struck the region. Evidently such extreme events have impacted the region about every 300 years, though not since 1895.

This example illustrates the limitations of using relatively short climate periods (~130 years) to assess the character and range of natural variability in general and of extreme events in particular. Accurate representation of the full range of natural variability is necessary for any attribution analyses (see 6.4). Infrastructure planners, emergency management institutions and attribution scientists would understand the significant mischaracterization of the magnitude of a future extreme if based only on the last 130 years. In this case, a single time-sample of 130 years provides an underestimation of the extreme value by up to 50% determined when adding only 45 more years of observations. Compared to millennial-scale paleoclimate evidence, an even greater underestimation would occur. An important lesson is that the climate can deliver great surprises on its own, even without human influences.

We examine occurrences of 5-day deluges as follows. In a 130-year span there are 26 5-year intervals. At each location we computed the 5-day precipitation totals throughout the year and selected the 26 highest values. A single year may have more than one of the 26 heaviest. Each of those can be thought of as 1-in-5yr events. If there are no trends in precipitation then the total number of these events across all stations should be evenly spread out over the years. In Fig. 8.4.55.1 we show the distribution in time of these events. The deluges associated with the massive 1997-98 El Niño event are readily apparent. While erratic, as is typical of these types of precipitation metrics, there is no indication of a tendency to become more frequent over time.

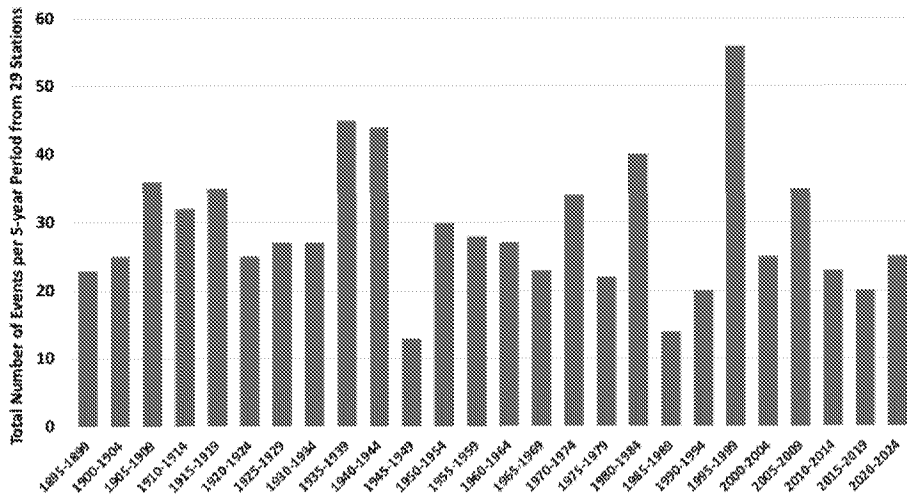


Figure 8.5.24.5. The time distribution by 5-year periods of the 26 heaviest occurrences for each station (i.e., nominal 1-in-5 year event).

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Southeast heavy rainfall events

The temporal pattern of 5-day totals of the 1-in-5yr heavy events in the humid Southeast (Figure 8.4.65.2) is generally unremarkable, though a cluster of higher values appears in 1995 to 2019. The increase in those years is due largely to the 4 northeastern-most stations of Wilmington NC, Weldon NC, Washington DC, and Norfolk VA. This confirms the pattern indicated in NCA4 and NCA5 of a tendency for an increasing frequency of heavy events, due to a temporal clustering of tropical storms from eastern NC to Maine discussed below. Otherwise, the remaining 20 stations show an unremarkable temporal distribution of heavy events.

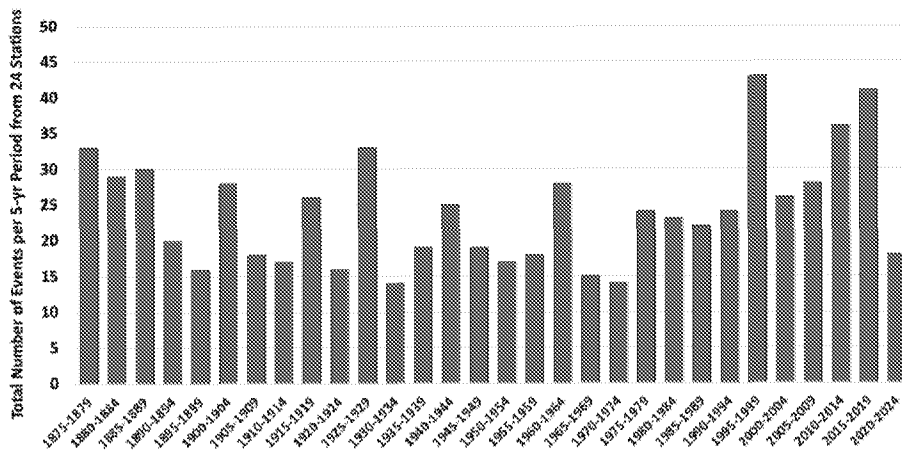


Figure 8.4-65.3. As above but for the 30 heaviest 1-in-5yr events for 24 stations in the humid Southeast from Austin TX to Washington DC in 5-year bins for 1875-2024.

Northwest heavy rainfall events

Fig. 8.4-75.3 shows the 27 (1-in-5yr) heaviest 3-day events for the last 135 years in 21 stations in the Northeast (including Montreal Canada). We use 3-day totals here as this produced the largest variations in time. In this region, 72% of the events occur during June to October and are dominated by tropical incursions of hurricanes, tropical storms or tropical storms that transition to extratropical systems. According to NCA4 and NCA5 this region experienced the largest increases in extreme events, so it shall be examined more closely.

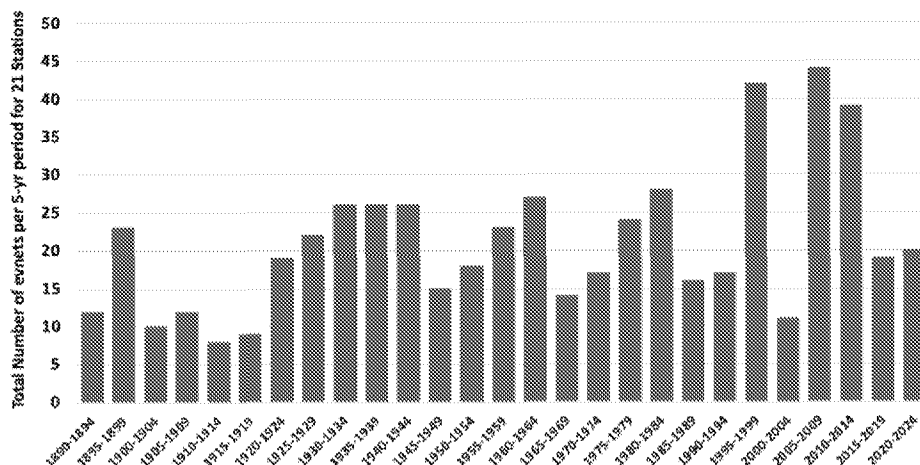


Figure 8.4-75.4. Time distribution of the heaviest 27 (1-in-5yr) heaviest 3-day precipitation events for 21 stations from NY to ME, including Montreal.

Howarth et al. (2019) report differences in the Northeast between two 18-year periods: 1979-96 and 1997-2014 (a similar region as in Fig. 8.16 that includes PA and NJ) of various precipitation extremes. One metric which indicated a dramatic increase (317%) was found for 24-hr events > 6 inches. This high increase is due to the very small numbers of such events of which there were only 6 in the first period and 25 in the second as reported for 58 stations. This high percentage increase is due to the very small numbers of the events; only 6 in the first period and 25 in the second. Most of the stations did not record such an event suggesting these erratic, episodic events over brief, 18-yr periods, need scrutiny by additional statistical methods.

Using the information in Fig. 8.4-75.4 over the same years as Howarth et al. we find a 51% increase in the frequency of heavy events between the two periods. One can see in Fig. 8.16 that it was unfortunate that Howarth et al. ended in 2014 prior to a return to the long-term average of such events.

A feature of Howarth et al. is the use of single day totals which is questionable because extreme events are often spread across the time-of-observation boundary. Thus stations measuring at 0700 LT versus those at Midnight will have differing results for a particular event which would then have major impacts on counting these events. We use the 3-day totals in Fig. 8.4-75.4 to be sure to capture the extent of these extreme downpours. In any case, we can confirm that the period 1997 to 2014 experienced a cluster of heavier events as Howarth et al. have documented.

Howarth's most remarkable claim (317% increase in 6" days) is potentially misleading because it is a threshold statistic (see Section 8.4.2-8.3.2 above) and a ratio of small numbers over a short period. The result is not representative of relative extreme events for the whole region since the majority of stations never experienced a 6" total. Figure 8.4-55.54 above determines the same number of events for each station (27 heaviest events) whose heaviest values ranged from 4.4" to 12.5" and their 27th heaviest values ranged from 3.3" to 5.0". This analysis thus allows each station to

be equally represented. In other words, if there is a region-wide increase in heavy events, it should be seen in the sum of all stations. Note too that the period of record here is 135 years vs. 36 years of Howarth et al. Except for three 5-year periods between 1995 and 2014 there is nothing statistically remarkable about the results in Fig. 8.4.7.

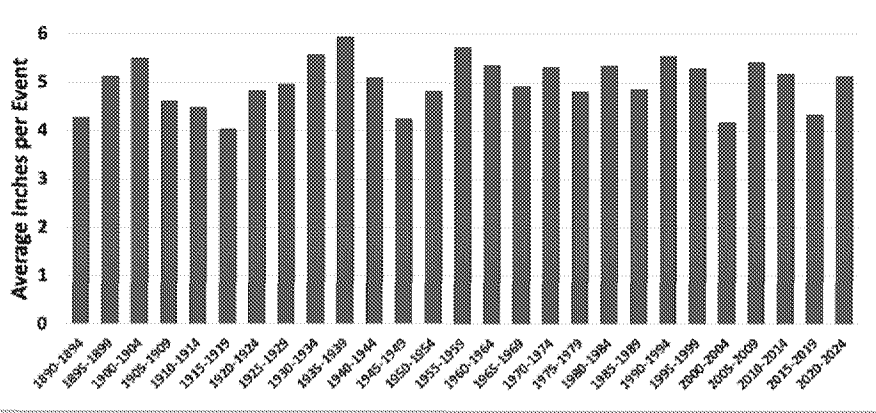


Figure 8.4.85.5. Average amount of precipitation falling in the 1-in-5yr events for the NE stations.

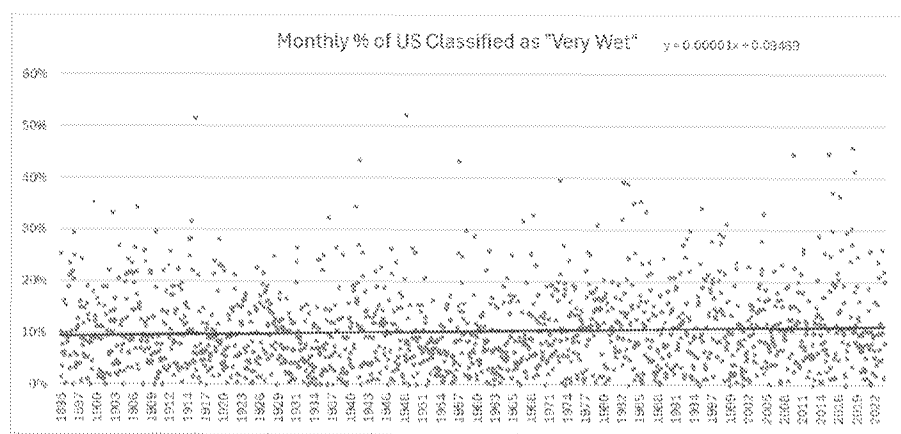
An interesting aspect of Northeast precipitation is that there has been no change in the amount of precipitation per heaviest event, as shown in Fig. 8.4.85.5. The trend is only $+0.02''/\text{decade}$. The highest amount, 1935-39, includes the Great New England Hurricane of 1938, one of the rare major (Category 3 or higher) hurricanes to strike the region. The results in Figs. 8.4.65.4 and 8.4.75.5 suggest that though there was an uptick in the number of events during the period 1995 to 2014, the events, individually, are not becoming more intense.

long et al. (2024) document the increase of tropical influences on precipitation events in the Northeast since 1959 and concluded, "The autumn extreme precipitation trend over the Northeast US is primarily attributed to tropical cyclone-related events since the 1990s." The question then becomes, was the temporal clustering of tropical systems in 1997-2014 which affected the Northeast a response to increasing GHGs? long et al. examined CMIP-6 model output which suggests that there will be fewer such systems in the 21st century but that the intensity of the rainfall events might increase. This conjecture is not seen in Fig. 8.17 where the amount-per-event has remained steady over the 135-year period.

For substantial urban areas there is some evidence to indicate the heaviest rainfall events may be redistributed due to the impact urban infrastructure has on the local weather (e.g., Pielke Sr. et al. 2011, Zhang et al. 2018, Yang et al. 2024). Yang et al. state, "Cities that experience compact development tend to witness larger increases in extreme rainfall frequency over downtown than their rural surroundings, while the anomalies in extreme rainfall frequency diminish for cities with

dispersed development." While this is an important insight to consider, the effect on the specific stations used in this analysis is unknown, or at least not detectable in Fig. 8.17.

In summary, the evidence from the historical record of extreme precipitation events in the CONUS is generally not consistent from region to region so that inferences regarding trends and their projections are wrought with significant uncertainty. In most regions and perhaps all, it is our opinion that the very nature of the erratic and episodic character of extreme precipitation events renders the discovery of statistically significant changes, including a relationship to CO2 concentrations, a result yet to be achieved (McKittrick and Christy 2019).



8.6 Tornadoes

AR6: [O]bservational trends in tornadoes, hail, and lightning associated with severe convective storms are **not robustly detected** due to insufficient coverage of the long-term observations. There is *medium confidence* that the mean annual number of tornadoes in the USA has remained relatively constant. (Chapter 11, section 11.7.3, p. 1594)

As noted there is no evidence of trends in US tornadoes or extreme convective storms.

Figure 8.3.84.1: Long-term US wetness (%). Source: NOAA [HYPERLINK "<https://www.ncei.noaa.gov/access/monitoring/uspa/wet-dry/0/>"]

8.2.27 Flooding

Changes in floods were assessed as follows:

AR6: "The SREX assessed *low confidence* for observed changes in the magnitude or frequency of floods at the global scale. This assessment was confirmed by the AR5 report. The SRI 5 found increases in flood frequency and extreme streamflow in some regions, but decreases in other regions. . . [H]ydrological literature on observed flood changes is heterogeneous, focusing at regional and sub-regional basin scales, making it difficult to synthesise at the global and sometimes regional scales." (Chapter 11.5)

AR6: "[T]he seasonality of floods has changed in cold regions where snowmelt dominates the flow regime in response to warming (*high confidence*). Confidence about peak flow trends over past decades on the global scale is *low*." (Chapter 11.5)

NCA 17: "Trends in extreme high values of streamflow are **mixed** across the United States. Analysis of 200 U.S. stream gauges indicates areas of both increasing and decreasing flooding magnitude but does not provide robust evidence that these trends are attributable to human influences" (pp. 240-241)

The absence of detectable US-wide trends in flooding is consistent with the findings in the previous section of absence of coherent changes in extreme precipitation.

SREX (p. 176)

In the United States and Canada during the 20th century and in the early 21st century, there is no compelling evidence for climate-driven changes in the magnitude or frequency of floods.

AR5 (p. 214)

AR4 WGI Chapter 3 (Trenberth et al., 2007) did not assess changes in floods but AR4 WGI concluded that **there was not a general global trend in the incidence of floods** (Kundzewicz et al., 2007). SREX went further to suggest that there was low agreement and thus *low confidence* at the global scale regarding changes in the magnitude or frequency of floods or even the sign of changes.

AR5 WGI assesses floods in regional detail accounting for the fact that trends in floods are strongly influenced by changes in river management (see also Section 2.5.2). Although the most evident flood trends appear to be in northern high latitudes, where observed warming trends have been largest, in some regions no evidence of a trend in extreme flooding has been found, for example, over Russia based on daily river discharge (Shiklomanov et al., 2007). Other studies for Europe (Hannaford and Marsh, 2008; Renard et al., 2008; Petrow and Merz, 2009; Stahl et al., 2010) and Asia (Jiang et al., 2008; Delgado et al., 2010) show evidence for upward, downward or no trend in the magnitude and frequency of floods, so that there is

currently no clear and widespread evidence for observed changes in flooding except for the earlier spring flow in snow-dominated regions (Seneviratne et al., 2012). In summary, there continues to be a lack of evidence and thus low confidence regarding the sign of trend in the magnitude and/or frequency of floods on a global scale.

AR6 (Ch 11 p. 1568)

The SR5X (Seneviratne et al., 2012) assessed low confidence for observed changes in the magnitude or frequency of floods at the global scale. This assessment was confirmed by the AR5 report (Hartmann et al., 2013). The SR15 (Hoegh-Guldberg et al., 2019) found increases in flood frequency and extreme streamflow in some regions, but decreases in other regions. While the number of studies on flood trends has increased since the AR5 report, and there were also new analyses after the release of SR15 (Berghuijs et al., 2017; Blöschl et al., 2019; Gudmundsson et al., 2019), hydrological literature on observed flood changes is heterogeneous, focusing at regional and sub-regional basin scales, making it difficult to synthesise at the global and sometimes regional scales.

In summary, the seasonality of floods has changed in cold regions where snow melt dominates the flow regime in response to warming (high confidence). Confidence about peak flow trends over past decades on the global scale is low, but there are regions experiencing increases, including parts of Asia, southern South America, the northeast USA, northwestern Europe, and the Amazon, and regions experiencing decreases, including parts of the Mediterranean, Australia, Africa, and the southwestern USA.

US NCA17, pp. 240-41:

"The IPCC AR5 did not attribute changes in flooding to anthropogenic influence nor report detectable changes in flooding magnitude, duration, or frequency. Trends in extreme high values of streamflow are mixed across the United States. Analysis of 200 U.S. stream gauges indicates areas of both increasing and decreasing flooding magnitude but does not provide robust evidence that these trends are attributable to human influences."

The complex mix of processes complicates the formal attribution of observed flooding trends to anthropogenic climate change and suggests that additional scientific rigor is needed in flood attribution studies. As noted above, precipitation increases have been found to strongly influence changes in flood statistics. However, in U.S. regions, no formal attribution of precipitation changes to anthropogenic forcing has been made so far, so indirect attribution of flooding changes is not possible. Hence, no formal attribution of observed flooding changes to anthropogenic forcing has been claimed."

8.2.3 Heatwaves

AR5 (p. 212 WG1)

Table 2.13 shows that there has been a likely increasing trend in the frequency of heatwaves since the middle of the 20th century in Europe and Australia and across much of Asia where there are sufficient data. However, confidence on a global scale is medium owing to lack of studies over Africa and South America but also in part owing to differences in trends depending on how heatwaves are defined (Perkins et al., 2012). Using monthly means as a proxy for heatwaves Coumou et al. (2013) and Hansen et al. (2012) indicate that record-breaking temperatures in recent decades substantially exceed what would be expected by chance but caution is required when making inferences between these studies and those that

deal with multi-day events and/or use more complex definitions for heatwave events. There is also evidence in some regions that periods prior to the 1950s had more heatwaves (e.g., over the USA, the decade of the 1930s stands out and is also associated with extreme drought conditions (Peterson et al., 2013) whereas conversely in other regions heatwave trends may have been underestimated owing to poor quality and/or consistency of data (e.g., Della-Marta et al. (2007a) over Western Europe; Kuglitsch et al. (2009, 2010) over the Mediterranean). Recent available studies also suggest that the number of cold spells has reduced significantly since the 1950s (Donat et al., 2013a, 2013c).

In summary, new analyses continue to support the AR4 and SREX conclusions that since about 1950 it is very likely that the numbers of cold days and nights have decreased and the numbers of warm days and nights have increased overall on the global scale, that is, for land areas with sufficient data. It is likely that such changes have also occurred across most of North America, Europe, Asia and Australia.

NCA17 (pp. 190–191)

Changes in warm extremes are more nuanced than changes in cold extremes. For instance, the warmest daily temperature of the year increased in some parts of the West over the past century (Figure 6.3), but there were decreases in almost all locations east of the Rocky Mountains. In fact, all eastern regions experienced a net decrease (Table 6.2), most notably the Midwest (about 2.2°F [1.2°C]) and the Southeast (roughly 1.5°F [0.8°C]). The decreases in the eastern half of [the] Nation, particularly in the Great Plains, are mainly tied to the unprecedented summer heat of the 1930s Dust Bowl era, which was exacerbated by land-surface feedbacks driven by springtime precipitation deficits and land mismanagement. However, anthropogenic aerosol forcing may also have reduced summer temperatures in the Northeast and Southeast from the early 1950s to the mid-1970s, and agricultural intensification may have suppressed the hottest extremes in the Midwest.

Since the mid-1960s, there has been only a very slight increase in the warmest daily temperature of the year (amidst large interannual variability). Heat waves (6-day periods with a maximum temperature above the 90th percentile for 1961–1990) increased in frequency until the mid-1930s, became considerably less common through the mid-1960s, and increased in frequency again thereafter (Figure 6.4). As with warm daily temperatures, heat wave magnitude reached a maximum in the 1930s.

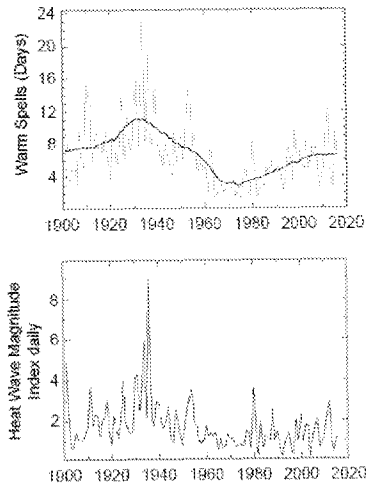


Figure 8.2.1: US Heat waves since 1900. Source: NCA17 Figure 6.4

AR6 (p. 1550)

In North America (Table 11.19), there is very robust evidence for a *very likely* increase in the intensity and frequency of hot extremes and decrease in the intensity and frequency of cold extremes for the whole continent, though there are substantial spatial and seasonal variations in the trends. Minimum temperatures display warming consistently across the continent, while there are more contrasting trends in the annual maximum daily temperatures in parts of the USA (Figure 11.9; Lee et al., 2014; van Oldenborgh et al., 2019; Dunn et al., 2020).

8.2.4 Extreme snowfall events

Note: extreme snowfall events in the US northeast are assessed in relation to winter Extratropical Cyclone (ETC) activity.

AR6 Ch 11, p. 1593

There is *high confidence* that snowfall associated with winter ETCs will decrease in the future, because increases in tropospheric temperatures lead to a lower proportion of precipitation falling as snow (O’Gorman, 2014; Rhoades et al., 2018; Zarzycki, 2018). However, there is *medium confidence* that extreme snowfall events associated with winter ETCs will change little in regions where snowfall will be supported in the future (O’Gorman, 2014; Zarzycki, 2018).

8.2.5 Extreme precipitation

SREX (p. 142)

Recent studies have updated the assessment of the AR4, with more regional results now available (Table 3-2). Overall, this additional evidence confirms that **more locations and studies show an increase than a decrease in extreme precipitation, but that there are also wide regional and seasonal variations**, and trends in many regions are not statistically significant (Table 3-2). Based on station data from Canada, the United States, and Mexico, Peterson et al. (2008a) reported that heavy precipitation has been increasing over 1950-2004, as well as the average amount of precipitation falling on days with precipitation.

AR5 (pp. 213-14)

In summary, further analyses continue to support the AR4 and SREX conclusions that **it is likely that since 1951 there have been statistically significant increases in the number of heavy precipitation events (e.g., above the 95th percentile) in more regions than there have been statistically significant decreases, but there are strong regional and subregional variations in the trends**. In particular, many regions present statistically non-significant or negative trends, and, where seasonal changes have been assessed, there are also variations between seasons (e.g., more consistent trends in winter than in summer in Europe). The overall most consistent trends towards heavier precipitation events are found in central North America (very likely increase) but assessment for Europe shows likely increases in more regions than decreases.

AR6 (p. 1560)

In North America, there is robust evidence that the magnitude and intensity of extreme precipitation has *very likely* increased since the 1950s. Both [one-day maximal] and [5-day maximal] have significantly increased in North America during 1950-2018 (Sun et al., 2020, also Figure 11.13). There is, however, regional diversity. In Canada, there is a lack of detectable trends in observed annual maximum daily (or shorter duration) precipitation (Shephard et al., 2014; Mekis et al., 2015; Vincent et al., 2018).

NC417 pp. 213-14:

Detectability of trends (compared to internal variability) for a number of precipitation metrics over the continental United States has been examined; **however, trends identified for the U.S. regions have not been clearly attributed to anthropogenic forcing**. One study concluded that increasing precipitation trends in some north-central U.S. regions and the extreme annual anomalies there in 2013 were at least partly attributable to the combination of anthropogenic and natural forcing. **Based on current evidence, it is concluded that detectable but not attributable increases in mean precipitation have occurred over parts of the central United States**. Formal detection-attribution studies indicate a human contribution to extreme precipitation increases over the continental United States, but confidence is low based on those studies alone due to the short observational period, high natural variability, and model uncertainty.

In summary, based on available studies, it is concluded that for the continental United States there is *high confidence* in the detection of extreme precipitation increases, while there is *low confidence* in attributing the extreme precipitation changes purely to anthropogenic forcing.

8.2.6 Tornadoes and severe convective storms

Severe convective storms are convective systems that are associated with extreme phenomena such as tornadoes, hail, heavy precipitation (rain or snow), strong winds, and lightning.

The assessment of changes in severe convective storms in SREX (Chapter 3, Seneviratne et al., 2012) and AR5 (Chapter 12, Collins et al., 2013) is limited and focused mainly on tornadoes and hail storms. The SREX assessed that **there is low confidence in observed trends in tornadoes and hail** because of data inhomogeneities and inadequacies in monitoring systems. Subsequent literature assessed in the Climate Science Special Report (Kossin et al., 2017) led to the assessment of the observed tornado activity over the 2000s in the USA, with a decrease in the number of days per year with tornadoes and an increase in the number of tornadoes on these days (*medium confidence*). However, **there is low confidence in past trends for hail and severe thunderstorm winds**. Climate models consistently project environmental changes that would support an increase in the frequency and intensity of severe thunderstorms that combine tornadoes, hail, and winds (*high confidence*), but there is *low confidence* in the details of the projected increase.

In summary, because the definition of severe convective storms varies depending on the literature and the region, it is not straightforward to make a synthesizing view of observed trends in severe convective storms in different regions. In particular, **observational trends in tornadoes, hail, and lightning associated with severe convective storms are not robustly detected** due to insufficient coverage of the long-term observations. There is *medium confidence* that the mean annual number of tornadoes in the USA has remained relatively constant, but their variability of occurrence has increased since the 1970s, particularly over the 2000s, with a **decrease in the number of days per year, and an increase in the number of tornadoes on these days** (*high confidence*). Detected tornadoes have also increased in Europe, but the trend depends on the density of observations.

In summary, **it is extremely difficult to detect and attribute changes in severe convective storms**. There is limited evidence that extreme precipitation associated with severe convective storms has increased in some cases.

8.2.7 Hurricanes and Tropical Cyclones

SREX (p. 150):

There have been no significant trends observed in global tropical cyclone frequency records, including over the present 40-year period of satellite observations (e.g., Webster et al., 2005). Regional trends in tropical cyclone frequency have been identified in the North Atlantic, but the fidelity of these trends is debated (Holland and Webster, 2002; Landsea, 2007; Mann et al., 2007a). Different methods for estimating undercounts in the earlier part of the North Atlantic tropical cyclone record provide mixed conclusions (Chang and Gao, 2007; Mann et al., 2007b; Kunkel et al., 2008; Vecchi and Knutson, 2008). Regional trends have not been detected in other oceans (Chan and Xu, 2009; Kubota and Chan, 2009; Callaghan and Power, 2011). It thus remains uncertain whether any observed increases in tropical cyclone frequency on time scales longer than about 40 years are robust after accounting for past changes in observing capabilities (Knutson et al., 2010).

AR5 (pp. 216–17):

Current data sets indicate no significant observed trends in global tropical cyclone frequency over the past century and it remains uncertain whether any reported long-term increases in tropical cyclone frequency are robust after accounting for past changes in observing capabilities (Knutson et al., 2010). No robust trends in annual numbers of tropical storms, hurricanes and major hurricanes counts have been identified over the past 100 years in the North Atlantic basin. Measures of land-falling tropical cyclone frequency (Figure 2.24) are generally considered to be more reliable than counts of all storms which tend to be strongly influenced by those that are weak and/or short-lived. Callaghan and Power (2011) find a statistically significant decrease in Eastern Australia land-falling tropical cyclones since the late 19th century although including 2010/2011 season data this trend becomes non-significant (i.e. a trend of zero lies just inside the 90% confidence interval). Significant trends are not found in other oceans on shorter time scales (Chan and Xu, 2009; Kubota and Chan, 2009; Mohapatra et al., 2011; Weinkle et al., 2012), although Grinstead et al. (2012) find a significant positive trend in eastern USA using tide-gauge data from 1920–2009 as a proxy for storm surges associated with land-falling hurricanes. Differences between tropical cyclone studies highlight the challenges that still lie ahead in assessing long-term trends.

In summary, this assessment does not revise the SREX conclusion of low confidence that any reported long-term (centennial) increases in tropical cyclone activity are robust after accounting for past changes in observing capabilities. More recent assessments indicate that it is unlikely that annual numbers of tropical storms, hurricanes and major hurricanes counts have increased over the past 100 years in the North Atlantic basin. Evidence, however, is for a virtually certain increase in the frequency and intensity of the strongest tropical cyclones since the 1970s in that region.

AR6 (p. 1585)

There is low confidence in most reported long-term (multidecadal to centennial) trends in TC frequency or intensity-based metrics due to changes in the technology used to collect the best-track data. This should not be interpreted as implying that no physical (real) trends exist, but rather as indicating that either the quality or the temporal length of the data is not adequate to provide robust trend detection statements, particularly in the presence of multidecadal variability.

There are previous and ongoing efforts to homogenize the best-track data (Elsner et al., 2008; Kossin et al., 2012, 2020; Chou et al., 2015; Landsea, 2015; Emanuel et al., 2019) and there is substantial literature that finds positive trends in intensity-related metrics in the best-track during the “satellite period”, which is generally limited to the past 40 years (Kang and Elsner, 2012; Kishitani et al., 2012; Kossin et al., 2012, 2020; Mei and Xie, 2016; Zhao et al., 2018; Tawale and Teubok, 2019). When best-track trends are tested using homogenized data, the intensity trends generally remain positive, but are smaller in amplitude (Kossin et al., 2012; Holland and Bruyere, 2014). Kossin et al. (2020) extended the homogenized TC intensity record to the period 1979–2017 and identified significant global increases in major TC exceedance probability of about 6% per decade. In

⁴The underlined text referenced a study (Kossin et al. 2020) that later retracted a portion of its findings. Those authors assembled a data set on global TC incidence spanning 1979 to 2017 from which they claimed that the global fraction of TCs reaching major status (Cat 3–5) rose from 2.7% during 1979–1997 to 3.1% during 1998–2017 and that the increase was statistically significant. However, closer examination of their results showed a significant increase only in the North Atlantic (1.8% to 3.4%) whereas changes in all other basins (Eastern

~~addition to trends in TC intensity, there is evidence that TC intensification rates and the frequency of rapid intensification events have increased within the satellite era (Kishore et al., 2012; Balaguru et al., 2018; Bhatia et al., 2018). The increase in intensification rates is found in the best track as well as the homogenized intensity data.~~

~~A subset of the best track data corresponding to hurricanes that have directly impacted the United States since 1900 is considered to be reliable, and shows no trend in the frequency of U.S. landfall events (Knutson et al., 2019).~~

8.2.968 Droughts

~~Assessments of drought trends were as follows.~~

~~AR6: "Few AR6 regions show observed increases in meteorological drought" (Section 11.9, p. 1575).~~

~~AR6: "Increasing trends in agricultural and ecological droughts have been observed on all continents (*medium confidence*), but decreases only in one AR6 region (*medium confidence*). Increasing trends in hydrological droughts have been observed in a few AR6 regions." (Chapter 11 Summary)~~

~~NCA17: "As a consequence of this increased precipitation, drought statistics over the entire CONUS have declined." (p. 233)~~

~~NCA17: "Recent droughts and associated heat waves have reached record intensity in some regions of the United States; however, by geographical scale and duration, the Dust Bowl era of the 1930s remains the benchmark drought and extreme heat event in the historical record (very high confidence)." (p. 231)~~

~~SREX: "From a paleoclimate perspective, recent droughts are **not unprecedented**, with severe 'megadroughts' reported in the paleoclimatic record for Europe, North America, and Australia." (p. 170)~~

~~US NCA17 REPORT (Ch. 8, Wehner et al. 2017)~~

~~p. 231:~~

~~Recent droughts and associated heat waves have reached record intensity in some regions of the United States; however, by geographical scale and duration, the Dust Bowl era of the 1930s remains the benchmark drought and extreme heat event in the historical record (very high confidence). While by some measures drought has decreased over much of the continental United States in association with long-term increases in precipitation, neither the precipitation increases nor inferred drought decreases have been confidently attributed to anthropogenic forcing.~~

~~Pacific, Western Pacific, North Indian, South Indian, South Pacific) were not statistically significant. In a subsequent correction ([HYPERLINK "https://www.pnas.org/doi/10.1073/pnas.2021573117"]), Kossin et al. stated that the global probability of observing a major TC rose from 34% during 1979-1997 to 37% in the later period and that the evidence for statistical significance was now weaker. Nevertheless, the authors claimed that the correction did not affect their conclusions.~~

The human effect on recent major U.S. droughts is complicated. Little evidence is found for a human influence on observed precipitation deficits, but much evidence is found for a human influence on surface soil moisture deficits due to increased evapotranspiration caused by higher temperatures. (High confidence)

p. 233:

Drought is, of course, directly connected to seasonal precipitation totals. Figure 7.1 shows detectable observed recent changes in seasonal precipitation. In fact, the increases in observed summer and fall precipitation are at odds with the projections in Figure 7.5. As a consequence of this increased precipitation, drought statistics over the entire CONUS have declined.

SREX (p. 170)

From a paleoclimate perspective recent droughts are not unprecedented, with severe 'megadroughts' reported in the paleoclimatic record for Europe, North America, and Australia (Jansen et al., 2007). Recent studies extend this observation to African and Indian droughts (Sinha et al., 2007; Shanahan et al., 2009); much more severe and longer droughts occurred in the past centuries with widespread ecological, political, and socioeconomic consequences. Overall, these studies confirm that in the last millennium several extreme droughts have occurred (Breda and Badeau, 2009; Kallis, 2008; Büntgen et al., 2010).

In North America, there is medium confidence that there has been an overall slight tendency toward less dryness (wetting trend with more soil moisture and runoff; Table 3-2), although analyses for some subregions also indicate tendencies toward increasing dryness. This assessment is based on several lines of evidence, including simulations with different hydrological models as well as PDSI and CDD estimates (Alexander et al., 2006; Andreadis and Lettenmaier, 2006; van der Schrier et al., 2006a; Kunkel et al., 2008; Sheffield and Wood, 2008a; Dai, 2011).

The most severe droughts in the 20th century have occurred in the 1930s and 1950s, where the 1930s Dust Bowl was most intense and the 1950s drought most persistent (Adreadis et al., 2005) in the United States, while in Mexico the 1950s and late 1990s were the driest periods. Recent regional trends toward more severe drought conditions were identified over southern and western Canada, Alaska, and Mexico, with subregional exceptions (Dai, 2011).

SREX (p. 172)

Overall, though new studies have furthered the understanding of the mechanisms leading to drought, there is still relatively limited evidence to provide an attribution of observed changes, in particular given the issues associated with the availability of observational data (Section 3.2.1) and the definition and computation of drought indicators (Box 3-3). This latter point was mostly identified in post-AR4 studies (Box 3-3). Moreover, regions where consistent increases in drought are identified (see 'Observed Changes') are only partly consistent with those where projections indicate an enhancement of drought conditions in coming decades (see next paragraphs). We thus assess that there is medium confidence (see also Section 3.1.5) that anthropogenic influence has contributed to some changes in the drought patterns observed in the second half of the 20th century, based on its attributed impact on precipitation and temperature changes (though temperature can only

be indirectly related to drought trends; see Box 3-3). However **there is low confidence in the attribution of changes in droughts at the level of individual regions.**

AR5 (pp. 214-215)

Based on evidence since AR4, SREX concluded that there were not enough direct observations of dryness to suggest high confidence in observed trends globally, although there was *medium confidence* that since the 1950s some regions of the world have experienced more intense and longer droughts. The differences between AR4 and SREX are due primarily to analyses post-AR4, differences in how both assessments considered drought and updated IPCC uncertainty guidance.

Because drought is a complex variable and can at best be incompletely represented by commonly used drought indices, discrepancies in the interpretation of changes can result. For example, Sheffield and Wood (2008) found decreasing trends in the duration, intensity and severity of drought globally. Conversely, Dai (2011a,b) found a general global increase in drought, although with substantial regional variation and individual events dominating trend signatures in some regions (e.g., the 1970s prolonged Sahel drought and the 1930s drought in the USA and Canadian Prairies). Studies subsequent to these continue to provide somewhat different conclusions on trends in global droughts and/or dryness since the middle of the 20th century (Sheffield et al., 2012; Dai, 2013; Donat et al., 2013c; van der Schrier et al., 2013).

In summary, the current assessment concludes that there is not enough evidence at present to suggest more than low confidence in a global-scale observed trend in drought or dryness (lack of rainfall) since the middle of the 20th century, owing to lack of direct observations, geographical inconsistencies in the trends, and dependencies of inferred trends on the index choice. Based on updated studies, AR4 conclusions regarding global increasing trends in drought since the 1970s were probably overstated. However, it is likely that the frequency and intensity of drought has increased in the Mediterranean and West Africa and decreased in central North America and north-west Australia since 1950.

AR6 (Drought, Observed trends, Section 11.6.2, pp. 1573-75)

p. 1573

Strong precipitation deficits have been recorded in recent decades in the Amazon (2005-2010), south-western China (2009-2010), south-western North America (2011-2014), Australia (1997-2009), California (2014), the middle East (2012-2016), Chile (2010-2015), the Great Horn of Africa (2011), among others (van Dijk et al., 2013; Mann and Gleick, 2015; Rowell et al., 2015; Marengo and Espinoza, 2016; Dai and Zhao, 2017; Garreaud et al., 2017, 2020; Marengo et al., 2017; Brito et al., 2018; Cook et al., 2018). **Global studies generally show no significant trends in SPI time series** (Orlowsky and Seneviratne, 2013; Spinoni et al., 2014), **and in derived drought frequency and severity data** (Spinoni et al., 2019), with very few regional exceptions (Section 11.9 and Figure 11.17).

p. 1574

For AR6 regions, several studies suggest an increase in the frequency and areal extent of soil moisture deficits, with examples in East Asia (Cheng et al., 2015; Y. Qin et al., 2015; Jia et al., 2018), Western and Central Europe (Trnka et al., 2015b), and the Mediterranean (Hanel et al., 2018; Moravec et al., 2019; Markonis et al., 2021). **Nonetheless, some analyses also show no long-term trends in soil drying in some AR6 regions – for example, in Eastern**

North America (Park Williams et al., 2017) and Central North America (Seager et al., 2019), as well as in North Eastern Africa (Kew et al., 2021).

There is evidence based on streamflow records of increased hydrological droughts in East Asia (D. Zhang et al., 2018) and southern Africa (Gudmundsson et al., 2019). In areas of Western and Central Europe and Northern Europe, there is no evidence of changes in the severity of hydrological droughts since 1950 based on flow reconstructions (Caillaud et al., 2017; Barker et al., 2019) and observations (Vicente-Serrano et al., 2019). In North America, depending on the methods, datasets and study periods, there are differences between studies that suggest an increase (Shukla et al., 2015; Udall and Overpeck, 2017) versus a decrease in hydrological drought frequency (Mo and Lettenmaier, 2018), but in general there is strong spatial variability (Poshtiri and Pal, 2016). Streamflow observation reference networks of near-natural catchments have also been used to isolate the effect of climate trends on hydrological drought trends in a few regions, but these show limited trends in Northern Europe and Western and Central Europe (Stahl et al., 2010; Bard et al., 2015; Harrigan et al., 2018), North America (Dudley et al., 2020) and most of Australia, with the exception of Eastern and Southern Australia (X.S. Zhang et al., 2016).

p. 1575

Few AR6 regions show observed increases in meteorological drought (Section 11.9), mostly in Africa and South America (NES: *high confidence*; WAF, CAF, ESAF, SAM, SWS, SSA, SAS: *medium confidence*); a few others show a decrease (WSB, ESB, NAU, CAU, NEU, CNA: *medium confidence*). There are stronger signals indicating observed increases in agricultural and ecological drought (Section 11.9), which highlights the role of increased [evapotranspiration] driven by increased [Atmospheric Evaporative Demand] for these trends (Sections 11.6.2.3, 11.6.2.5). Past increases in agricultural and ecological droughts are found on all continents and several regions (WAF, CAF, WSAF, ESAF, WCA, ECA, EAS, SAU, MED, WCE, NES: *medium confidence*), while decreases are found only in one AR6 region (NAU: *medium confidence*). The more limited availability of datasets makes it more difficult to assess historical trends in hydrological drought at regional scale (Section 11.9). Increasing (MED: *high confidence*; WAF, EAS, SAU: *medium confidence*) and decreasing (NEU, SES: *medium confidence*) trends in hydrological droughts have only been observed in a few regions.

AR6 on Attribution (p. 1577)

There are only two AR6 regions in which there is at least *medium confidence* that human-induced climate change has contributed to changes in meteorological droughts (Section 11.9). In South-western South America (SSW), there is *medium confidence* that human-induced climate change has contributed to an increase in meteorological droughts (Boisier et al., 2016; Garreaud et al., 2020), while in Northern Europe (NEU), there is *medium confidence* that it has contributed to a decrease in meteorological droughts (Gudmundsson and Seneviratne, 2016) (Section 11.9). In other AR6 regions, there is inconclusive evidence in the attribution of long-term trends, but a human contribution to single meteorological events or subregional trends has been identified in some instances. In North America, the human influence on precipitation deficits is complex (Wehner et al., 2017), with low confidence in the attribution of long-term changes in meteorological drought in AR6 regions.

As shown in Figure 8.3-968.1 US long term data (NOAA) shows an insignificantly declining tendency toward extreme dryness (-0.001% per year)

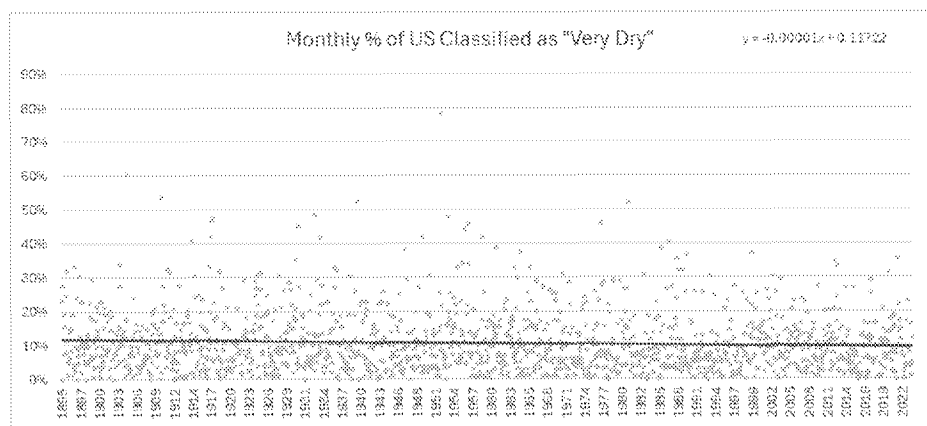


Figure 8.3-968.1: US dryness (%) 1895—2023. Source: NOAA [HYPERLINK "<https://www.ncei.noaa.gov/access/monitoring/uspa/wet-dry/0>"]

Kogan et al. (2020) examines a 38-year high-resolution satellite-based drought measure and concludes that global drought has not intensified and is not connected to climate change: "it is possible to state firmly that global and main grain countries' drought area and intensity trends have not been following global climate warmings since 1980's."

8.32 Extreme weather trends at global and continental indicators of scale extreme weather trends

8.32.1 Tropical Cyclones (TCs)

Hurricane strength records for the North Atlantic and the Western Pacific go back to 1950 and the record does not show an increase in either total or major TCs. Figure 8.3.1 was published by Roger Pielke Jr. as an update to the Best Track data series originally presented in Weinkle et al. (2012).

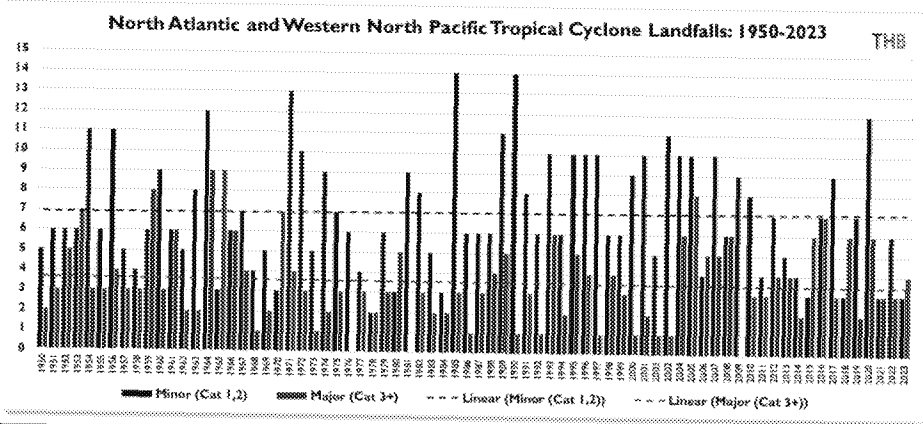


Figure 8.3.1. Tropical Cyclone Landfalls. Source: [HYPERLINK "https://rogerpielkejr.substack.com/p/global-tropical-cyclones"], Weinkle et al. (2012)

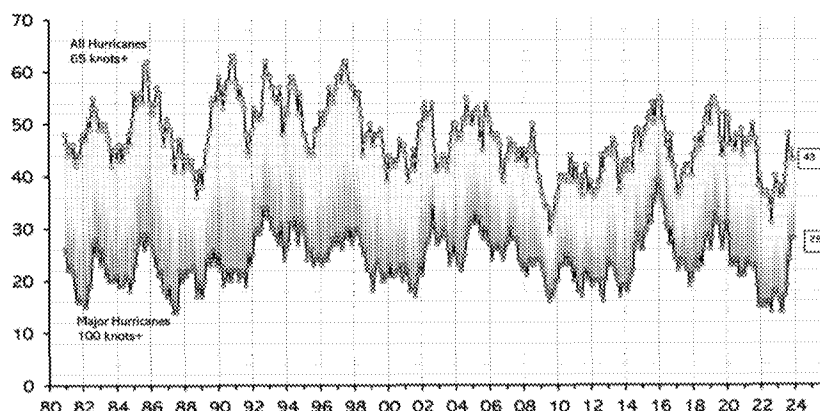
Similarly, [After 1980, as shown in Figure 8.3.2,]Maue 2025, [HYPERLINK "https://climatlas.com/tropical/"] shows that which reproduces data from the Climate Atlas of Dr. Ryan Maue both neither all hurricanes and the total number of hurricanes nor the frequency of major ones hurricanes have not become more common since 1980, the period of rapidly growing human influences. In fact, both numbers have trended down slightly since the 1990s:

Commented [A8]: One the Climate Atlas of Dr. Ryan Maue

Global Major Hurricane Frequency – 12 month running sums – @RyanMaue

Updated December 31, 2023

Last 30-years: 45.7 H | 24.4 M



Global Major Hurricane Frequency – 12 month running sums – @RyanMaue

Updated March 10, 2025

Last 30-years, annual: 45 H | 24 M

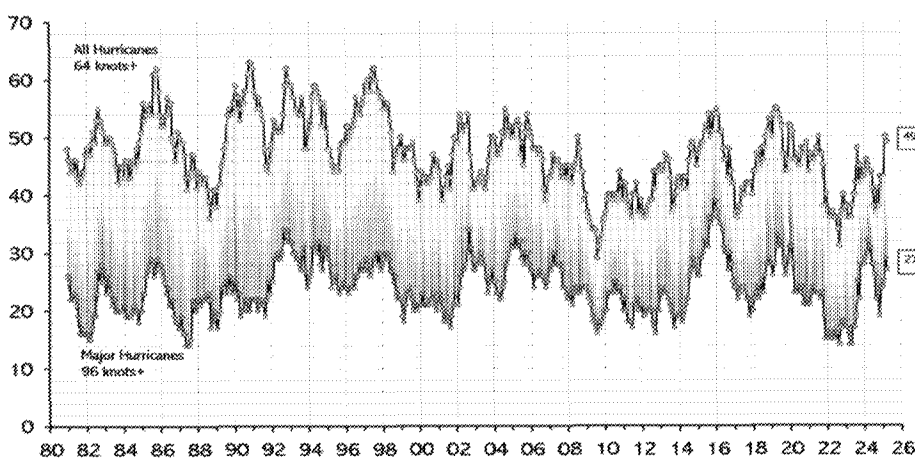


Figure 8.3.2: Global hurricane frequency. Source: Maue (2024/2025)

A metric that combines the number, duration, and frequency strength of TCs is the Accumulated Cyclone Energy (or ACE) Index maintained at Colorado State University, shown in Figure 8.3.3. As is clear, it is also not clearly shows no long-term increase, in fact declining slightly and since 1990 has declined slightly.

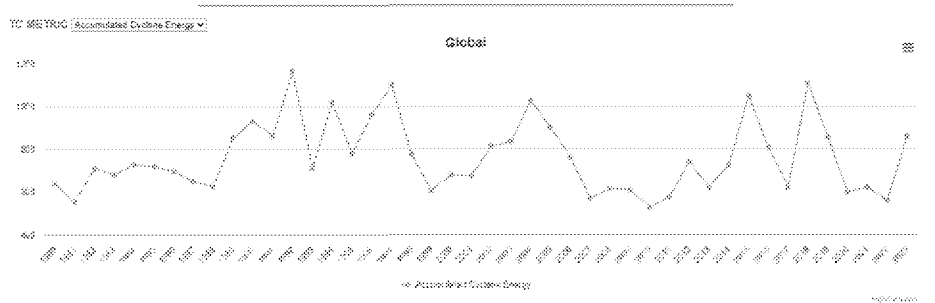


Figure 8.3.3: Global Accumulated Cyclone Energy. Source: Klotzbach (2025)
[HYPERLINK "<https://tropical.atmos.colostate.edu/Realtime/index.php?arch&loc=global>"]

Note that Tu et al. (2024) report that the Power Dissipation Index (PDI), another different measure of the destructiveness of hurricanes that combines hurricane number, duration, and strength, has either remained unchanged or has declined in all global oceanic basins since the mid-1990s. As is clear, it is also not increasing and since 1990 has declined slightly.

Today's global climate simulations are too coarse to project changes in TCs directly. Rather, projections are derived from finer "downscaled" simulations or proxies involving sea surface temperatures, winds, and aerosols. By those methods, a warming climate is expected to show climate models project declining hurricane formation rates in a warming climate (Chand et al. 2022). Climate models also project fewer Tropical Cyclones under future global warming, and even though models project they will increase in strength, the annual averages of rainfall maxima decline (Stansfield et al. 2020). Note that Tu et al. (2024) report that the Power Dissipation Index (PDI), a measure of the destructiveness of hurricanes, has either remained unchanged or has declined in all global oceanic basins since the mid-1990s.

8.23.279 Wildfires

The IPCC has not provided an assessment of wildfires.

As shown in Figures 8.3.479.1 and 8.3.5 global wildfire activity as measured by European Space Agency peaked over a decade ago and shows a downward trend since this century.

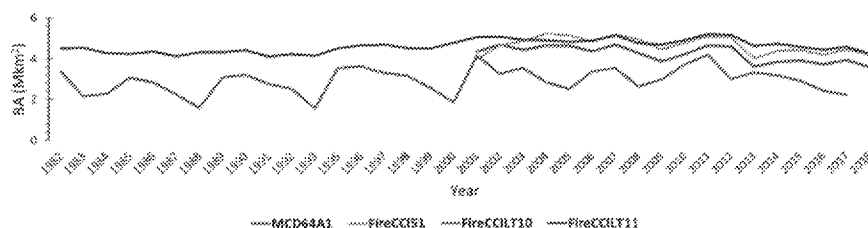


Figure 8.3.4: Global wildfire 1982-2018. Source: Copied from Oton et al. (2021). Note: the different coloured lines represent different data products based on satellites and algorithms used.

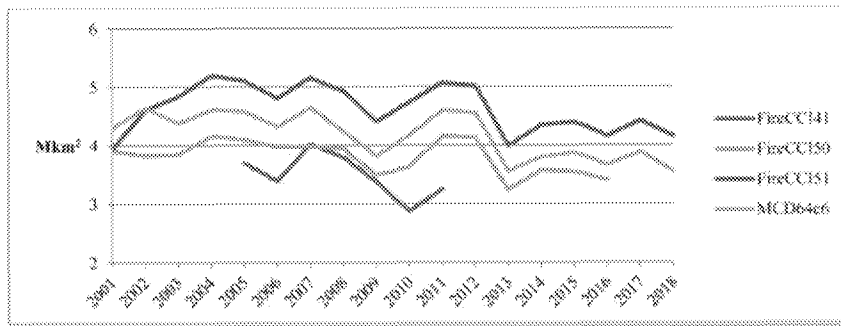


Figure 8.3.579.1: Global wildfire 2001-2018. Source: Copied from Lizundia-Loiola et al. (2021). Note: the different coloured lines represent different data products based on satellites and algorithms used.

US data from the National Interagency Fire Centre (NIFC) from 1926 to 2023 are shown in Figure 8.3.679.2.

Commented [A9]: I thought the trends were due to declining fires in the Amazon, masking any climate-related trend?

Commented [A10R9]: "global area burned appears to have overall declined over past decades, and there is increasing evidence that there is less fire in the global landscape today than centuries ago." Doerr and Santin, Proc Royal Society 2016

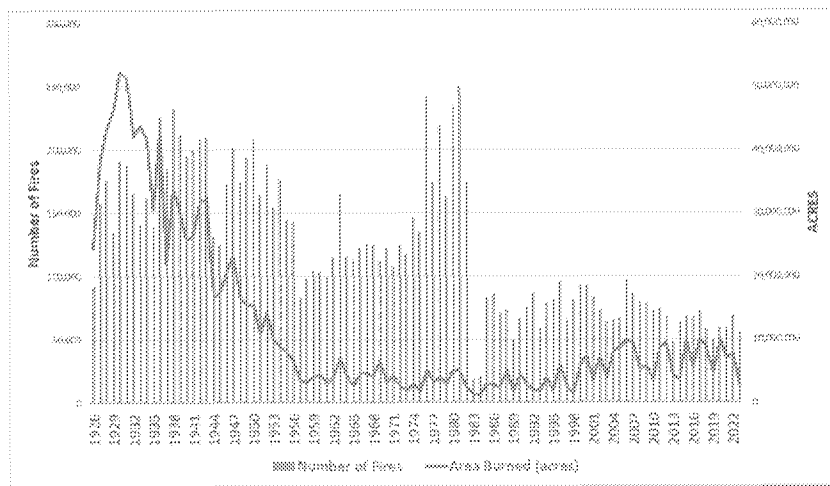


Figure 8.3.679.2: US wildfires 1926 to 2023. Source: National InterAgency Fire Centre data Pre-2017 (archived)

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HYPERLINK

2017):%20https:\\web.archive.org\\web\\20200212033452\\https:\\www.nifc.gov\\fireInfo\\fireInfo_stats_totalFires.html"]. 2018-2023: [HYPERLINK "https://www.nifc.gov/fire-information/statistics/wildfires"]

Note the NIFC has removed the pre-1960 data from its current website. They claim it is because measurement methods changed after 1960. This explanation seems inadequate since agencies blend temperature and extreme weather data series in other contexts when measurement systems changed. In this case if anything the measurement of wildfires has improved since the early 20th century so any bias will be towards understating early wildfire counts. Nonetheless just focusing on the post-1985 interval the number of fires is not increasing. The area burned did increase but only until about 2007.

It is difficult to establish a natural baseline for wildfire activity because of active fire suppression activity since 1900. Paleoclimatic evidence indicates, however, that past wildfire activity was much higher than at present. Marlon et al. (2012) used sedimentary charcoal layers to reconstruct fire history of western US for the past 1400 years. They also fit a model to predict expected fire activity as a function of climatic conditions. The results are summarized in Figure 8.3.79.3 below (from Figure 2 in their paper).

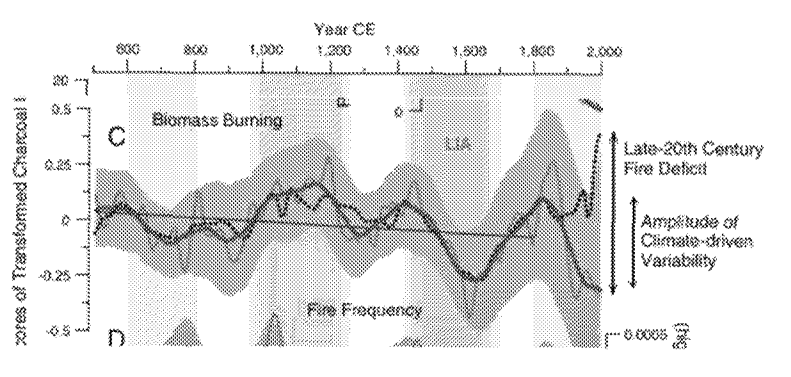


Figure 8.3.79.3 Fire frequency and fire deficit in the US. Source: Copied from Marlon et al. (2012)

In their figure the red line shows the smoothed charcoal record and the black dotted line shows the predicted charcoal record based on the statistical model. The gap at the end implies there has been a growing wildfire deficit over the 20th century. In other words, however much fire was observed in the 20th century it was less than what would have been observed in previous centuries based on the climatic conditions. Parks et al. (2025) likewise find that despite the recent increase in wildfire burn area in North America, a significant wildfire deficit remains relative to historical wildfire regimes there remains a significant wildfire deficit.

8.23.3 Precipitation

Figure 8.2.8 shows that US long-term data from NOAA shows an insignificantly increasing tendency toward extreme wetness (-0.001% per year)

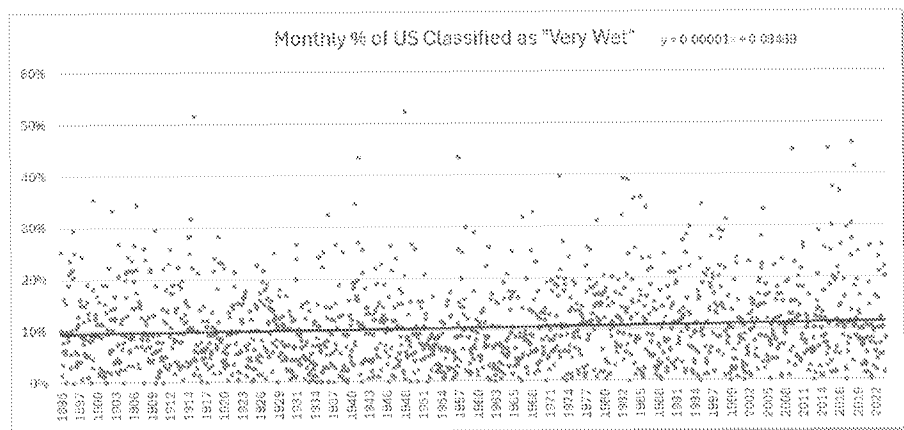


Figure 8.3.8: Long-term US wetness (%) Source: NOAA [HYPERLINK "<https://www.ncsl.noaa.gov/access/monitoring/uspa/wet-dry/0>"]

Precipitation will be discussed further in the review of CONUS data below.

8.23.4 Drought

As shown in Figure 8.3.9 US long-term data (NOAA) shows an insignificantly declining tendency toward extreme dryness (-0.001% per year)

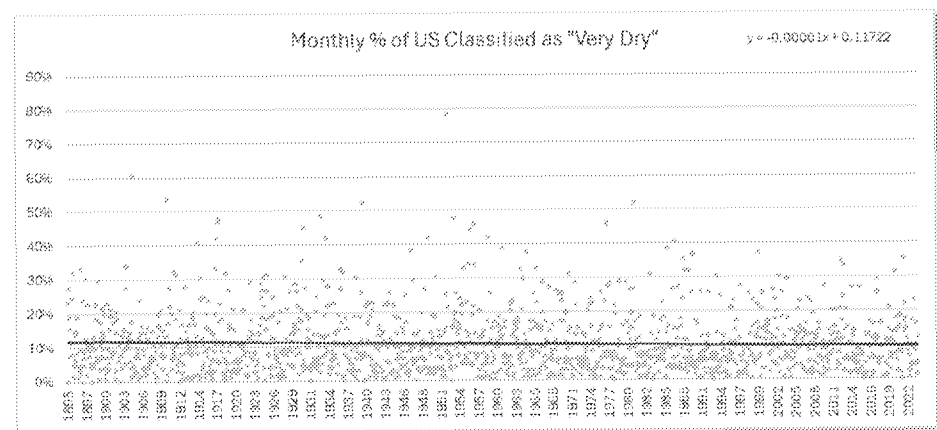


Figure 8.3.9: US dryness (%) 1865-2022 Source: NOAA [HYPERLINK "<https://www.ncsl.noaa.gov/access/monitoring/uspa/wet-dry/0>"]

~~Kogan et al. (2020) examines a 38-year high-resolution satellite-based drought measure and concludes that global drought has not intensified and is not connected to climate change. "It is possible to state firmly that global and main grain countries' drought area and intensity trends have not been following global climate warming since 1990's."~~

~~8.3.4 Analysis of Temperature and precipitation extremes in the Conterminous Contiguous US (CONUS) data on temperature and precipitation extremes~~

~~8.3.4.1 CONUS daily temperatures are becoming less extreme~~

~~Daily maximum temperatures in the warm season (TMax, May-Sep) and daily minimum temperatures in the cold season (TMin, Dec-Mar) are available beginning in Dec 1898 (126 years). [The dataset consists of 1,211 CONUS stations designated as United States Historical Climate Network or USHCN stations (Quinlan et al. 1987, Karl et al. 1990). These stations were selected by NOAA as having the fewest problematic issues with gaps, station moves and instrument changes. Where gaps still exist, nearby stations (bias-corrected) were merged so that the median volume of data available for a station is 98%. Although there are certainly errors certainly reside in the dataset, with over 1,000 stations we can have relatively high confidence in any underlying signal we that might be discovered can be characterized by relatively high confidence.~~

~~We begin with the question of whether the occurrence of daily record high or low temperatures changed has changed since Dec 1898. Each warm season has 153 days (1-May to 30-Sep) and each cold season has 122 days (1-Dec to 31-Mar). For each station and day, we calculated the year in which the record highest (lowest) temperature occurred. With 126 years of observations, if there were no temperature trends over time, the expected number of records for TMax would be 1.21 ($=153/126$) per station per year and for TMin 0.96 ($=122/126$) per station per year. Figure 8.4.110 indicates the observed distribution in time of the occurrence of these extreme events.~~

Commented [A11]: Again, I think we need a map of where the stations are; something like this one:
[HYPERLINK
"https://www.researchgate.net/publication/258660497_Uncertainties_Trends_and_Hottest_and_Coldest_Years_of_US_Surface_Air_Temperature_since_1895_An_Update_Based_on_the_USHCN_V2_TOB_Data/figures?no=1"]
More importantly, it needs to show how you've cut them up into regions.

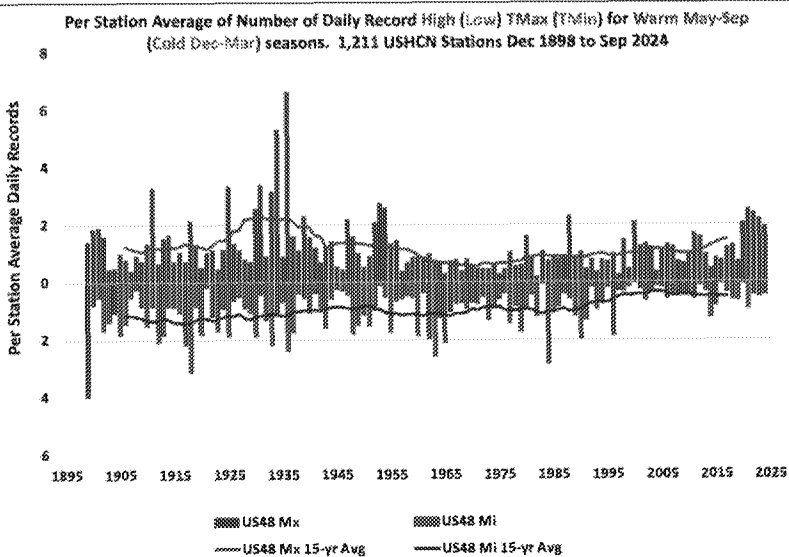
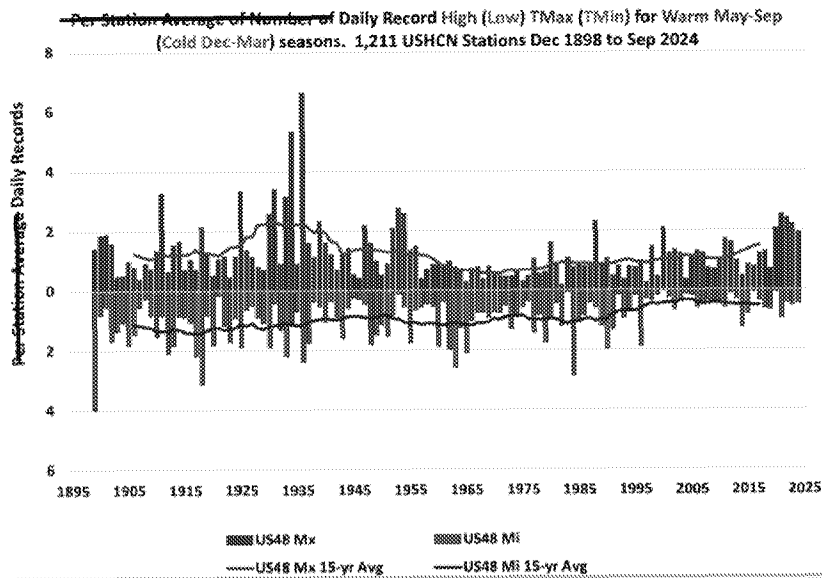


Figure 8.4.110 Number of daily record High (red) and Low (blue) for warm and cold seasons in the CONUS. The lines represent the 15-year running, centered average. Source: 1,211 USHCN stations supplemented as needed to achieve a minimum of 92% of observations in the 126-year period since Dec 1899.

The results indicate a common feature in many metrics of warm-season extremes in the CONUS—the exceptional heat of the 1920s and especially the 1930s, peaking in 1936. On a per-station average, 60% of the TMax records and 59% of the TMin records occurred in the first half of the period (1899–1961).

On the cold-side, the Valentine's Day Arctic outbreak in Feb 1899 stands as the most extensive cold extreme experienced by the CONUS, with 1917–2nd. The frequency of cold records has declined, especially over the last quarter of the period in which only 13% of the extreme cold events were measured. In contrast, 25% of the extreme TMax records were achieved in the last quarter in accordance with statistical expectations. These general features have been noted in past assessments (IPCC AR5, IPCC AR6, NCA4, NCA5). Combining the two records the overall reduction in numbers of both cold and hot extremes over the past century indicates a climate less prone to extremes.

This pattern is also shown in Figure 8.4.211. For each station and for each year the hottest warm season and coldest cold-season temperatures were calculated and converted to anomalies relative to the station's long-term warm and cold season (respectively) averages. Then the differences between these were computed by station and geographically averaged over all stations, thus yielding an annual measure of the expected range of local extreme temperatures for each year. Figure 8.11 shows the 15-year trailing average of this measure which has clearly declined over the past century.

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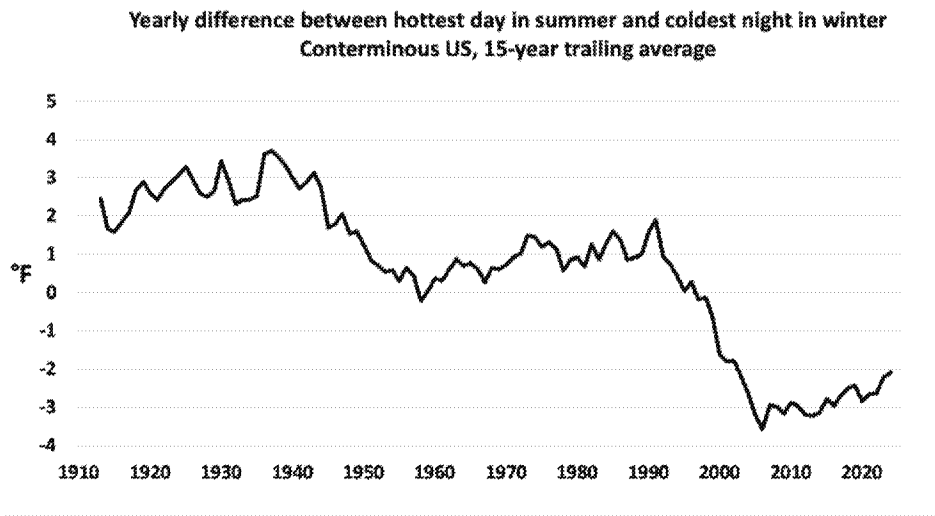


Figure 8.4.211. 15-year trailing average of the difference each year of each station's hottest warm-season TMax and coldest cold-season TMin relative to the long-term average.

The average difference for each station between the hottest summer TMax and coldest winter TMin has declined about 5°F in the past 126 years. The decline is due mostly to warming winter TMin, but

a decline in the magnitude of summer TMax is also a factor. The rise in TMin has been strongly related to the growing presence of manufactured surfaces around the weather stations over the last 100+ years (Spencer et al. 2025).

Summarizing Figures 8.10.4.1 and 8.4.2.11, while temperature extremes are regularly experienced in the US and attract a great deal of media attention, long term records show the US climate has become less extreme over time (milder) when measured in terms of the range between warm season maxima and cold season minima.

8.34.2 Exceedances of a heat threshold

Under the heading of "The Risk of Temperature Extremes is Changing", the most recent US National Climate Assessment report (NCA5) notes the increase in a threshold metric of number of days at or above 95°F, stating,

"The western US has been particularly affected by extreme heat since the 1980s ..., experiencing a larger increase in days over 95°F, as would be expected given the greater warming in that region relative to the eastern US. Several major heatwaves have affected the US since 2018, including a record-shattering event in the Pacific Northwest in 2021."

Are the occurrences of 95°F days changing? In a climate as varied as that of CONUS, threshold statistics can be misleading. A region with many stations which ~~that~~ have near 95°F TMax average temperatures in the summer might see large swings in the metric when only small changes in average temperature occur. Elsewhere with stations that either rarely or virtually always achieve 95°F TMax temperatures, a small change will not impact the results much at all. In the past 126 years, the average CONUS station experienced 129 days exceeding 95°F per 6-yr period, but the regional values range from 278 in the Southern Plains to 9 in the Northeast. Thus, one needs to view such threshold analyses with caution.

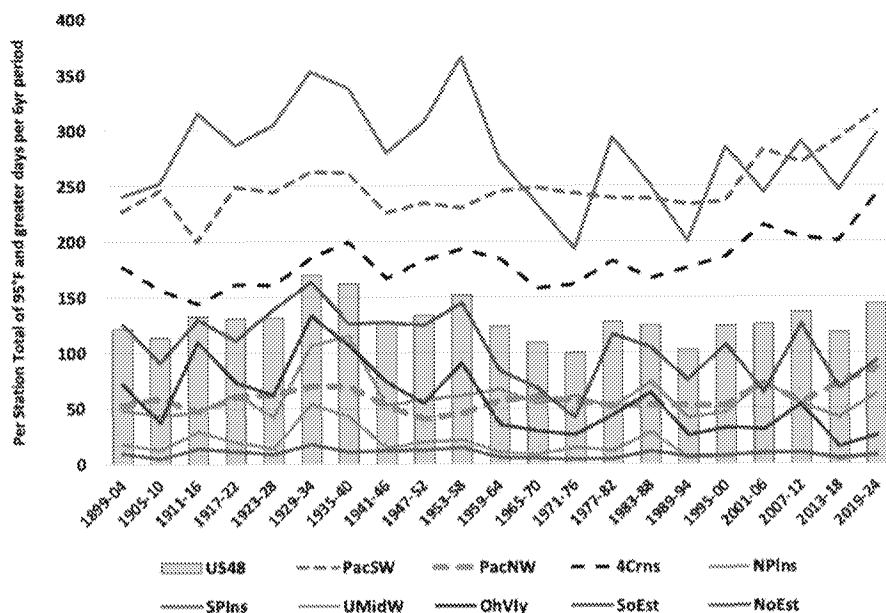


Figure 8.124.3. Total number of days $\geq 95^{\circ}\text{F}$ in 6-yr periods, US 48 (bars) and regions (lines).

In Fig. 8.12 4.3 we see that only three of the nine regions, all in the West, have experienced upward trends in the number of 95°F or hotter days (dashed lines). The CONUS as a whole has not and the other six regions have experienced declines.

The Pacific NW heatwave of 2021 is referenced as supportive information for of the NCA5 claim, an event we examined more closely in Section 6.4. The evidence indicates it was a “black swan” event, i.e., a single, unprecedented event in the existing record, not part of a suggesting it is not indicative of a pattern of increasing extreme heat. For example, the 5-day average tropospheric grid-point temperature anomaly over the Pacific NW during that event was $+10.8^{\circ}\text{C}$, the most extreme NH grid point summer anomaly in the 46 years from over 4 million grids. In contrast, the global anomaly during that time was virtually zero ($+0.03^{\circ}\text{C}$, Mass et al. 2024).

The heading “The Risk of Temperature Extremes is Changing” suggests positive trends are now being observed in threshold temperatures on a widespread basis, but that is not evidenced in the combined CONUS results of the figures above.

8.34.3 Heatwaves

Heatwaves (consecutive days that exceed an extreme threshold) have a greater societal impact than Of more impact than a single daily record. We measure is the phenomena of heatwaves, or consecutive days which exceed an extreme threshold. For this study, the metric will be the number of “Heatwave Days” here defined as the sum count of all days in May-Sep each year which that exceed

the 90th percentile and that occur lie within consecutive periods a run of at least six consecutive days in length. This is equivalent to the method used in NCA5 except that the reference period here is the entire record 1899-2024 while NCA5 limited truncated the reference period to 1961-1990, a cool episode time. By selecting 1961-1990, the that truncation occurrence of boosts positive results (days exceeding the 90th percentile) will be enhanced in periods warmer than the reference base period, especially if starting in 1960 and moving to the present (see *Urban Influences* below).

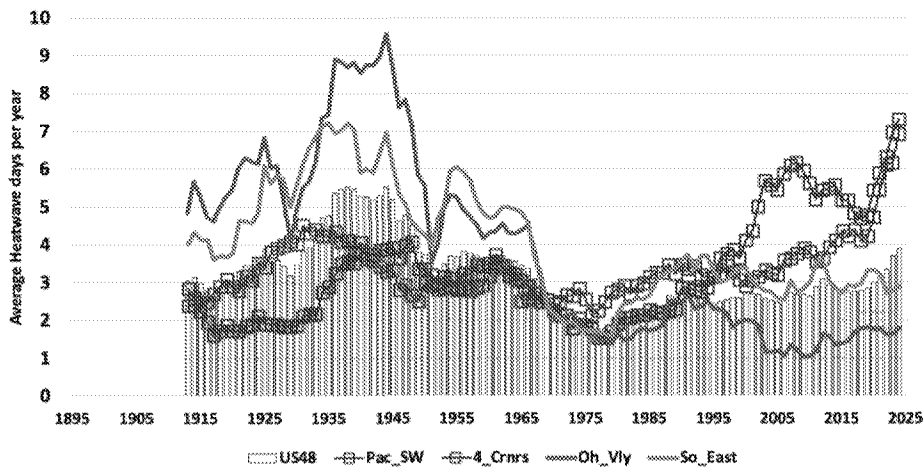


Figure 8.13 4.4 15-year trailing average of number of heatwave days per year per station in the CONUS (bars) and four regions: Pac_SW (purple squares, CA, NV), 4_Crnrs (red squares, AZ, NM, UT, CO), Oh_Vly (blue, MO, IL, KY, TN, IN, OH, WV) and So_East (green, MS, AL, GA, FL, SC, NC, VA).

Figure 8.13 4.4 indicates again the excessive heat of the first half of the 20th century, primarily in the eastern two-thirds of the nation, as seen in the regional values for the Ohio Valley and the Southeast as examples. The West has seen a recent increase of heatwave days and the two regions with the highest number are shown, the Pacific Southwest and the Four Corners (NCA5). This indicates that the background warm season circulation favored heatwaves in the eastern portions of the country in the first half of the 20th century, but in the 21st century the patterns have favored heatwaves in the West. For CONUS as a whole, heatwaves are no more common today than they were a century ago.

Of interest here is the regional variation of this metric. The four northern regions (Pacific NW, Northern Plains, Upper Midwest, and Northeast) on average experience 15 to 27 heatwave days per 15-year period. In contrast, the five southern regions (Pacific Southwest, 4-Corners, Southern Plains, Ohio Valley and Southeast) see 37 to 54 such days, essentially twice as many. This suggests the summer circulation pattern is more prone to stationary events in the southern regions while transient systems in the northern regions are more common and thus cut short these potentially longer events.

Urban influences

The NCA5 directs readers to the website [HYPERLINK "https://www.globalchange.gov/indicators/heat-waves"] (USGCRP 2023) to view the number of urban heatwaves by decade from the 1960s. The figure reveals shows a monotonic increase in each decade from 2 occurrences per year in the 1960s to 6 in the 2020s. The definition of a heatwave is an unusual but practical measure from a of human discomfort perspective – a period of at least 2 consecutive days when the minimum apparent minimum temperature (combination of temperature and humidity) exceeds the 85th percentile. Note too, the dataset is limited to the 50 largest U.S. cities in the US.

These increasing values since 1960 presented in USGCRP (2023) are entirely reasonable, but are unrelated to GHG emissions for at least two reasons unrelated to GHG emissions. Urbanization in these cities is a major factor in the rise of TMin relative to co-located TMax and relative to TMin at rural stations. Also, the 1960s was the coldest decade and 1970s the second coldest decade since the 1910's, so this starting date preconditions the time series to show increases. This does not dismiss the real rise in nighttime temperatures in major U.S. cities and the societal impacts associated with these changes. However, we note for a variety of reasons, that summer TMax (especially in rural areas) serves as better response variable for detecting potential changes in heatwaves influenced by changes in the background climate due, for example, to increasing GHGs (Christy et al. 2009). For the CONUS as a whole, the evidence in this section suggests GHG emissions have had little to no effect on heatwaves in the CONUS.

8.34.4 Extremes in daily precipitation.

Because precipitation involves a discrete phase change (water vapor to liquid), it is Due to its stochastic and episodic in character and therefore, precipitation requires careful statistical treatment to understand variability over long time periods (see 8.1 Introduction). The US National Climate Assessments (NCA4, NCA5) have highlighted an increase in the occurrence of the heaviest precipitation events (defined in different ways) primarily in the eastern half of the CONUS, especially the Northeast, when starting in either 1901 or 1958. Interestingly, the regional variations indicate that the largest increases in extreme events are in the Northeast and least the smallest in the West, which is a trend counter to the changes in temperature extremes shown above.

Commented [A13]: Stochasticity and LTP are really different things, but we somehow conflate them in this sentence. Or am I missing something?

Commented [A14R13]: By removing the 'therefore' I think we are now not conflating them.

McKittrick and Christy (2019) examined long-term and consistent station observations of daily precipitation to test some of these NCA claims for the Southeast and West Coast. In neither case when the time series were extended back in time (as far as 1872 in some cases) or when starting later (1978), there were no were the trends significant trends for either region. For this report we updated these findings with similarly constructed observations from 29 stations on the Pacific Coast (1893ff from San Diego CA to Blaine WA, see Figure 8.14), 24 stations in the humid Southeast (1872ff from Austin TX to Washington DC, see Figure 8.15), and 21 stations in the Northeast (1888ff from Buffalo NY to Gardiner ME, see Figure 8.16). The results were as follows:

Pacific region:

- Average precipitation trend is significant (downwards) in Astoria, insignificant elsewhere.
- The trend in rainfall variance is positive and significant in Big Sur, insignificant elsewhere.
- The trend in daily maximum precipitation is positive and significant in Aberdeen and Big Sur and negative and significant in Newport (insignificant elsewhere).
- Averaged over all stations in the region none of these three trend parameters is statistically significant.

Southeast region:

- ~~— The trend in average precipitation is positive and significant in Mobile and Quitman, insignificant elsewhere.~~
- ~~— The trend in rainfall variance is positive and significant in Mobile, insignificant elsewhere.~~
- ~~— The trend in daily maximum precipitation is positive and significant in Vicksburg and Norfolk, insignificant elsewhere.~~
- ~~— Averaged over all stations in the region none of these three trend parameters is statistically significant~~

Northeast region:

- ~~— The trend in average precipitation is positive and significant in 9 of 21 locations and in the region averaged overall.~~
- ~~— The trend in rainfall variance is positive and significant in Portland, Albany and Buffalo, insignificant elsewhere.~~
- ~~— The trend in daily maximum precipitation is positive and significant in Portland and Gardiner, insignificant elsewhere.~~
- ~~— Averaged over all stations in the region the trend parameters for variance and maximum precipitation are not statistically significant.~~

~~In the Pacific region, over the whole sample, the trend in average precipitation trends downward, being significant only is negative and significant in Astoria, and insignificant elsewhere. The trend in rainfall variance increases, is positive and significant only in Big Sur, and insignificant elsewhere. The trend in daily maximum precipitation is positive and significant in Aberdeen and Big Sur and negative and significant in Newport and insignificant elsewhere. Averaged over all stations in the region none of these three trend parameters is statistically significant.~~

~~In the Southeast region over the whole sample the trend in average precipitation is positive and significant only in Mobile and Quitman, the trend in rainfall variance is positive and significant only in Mobile and the trend in daily maximum precipitation is positive and significant only in Vicksburg and Norfolk. Averaged over all stations in the region none of these three trend parameters is statistically significant.~~

~~The Northeast region exhibits a pattern of increasing average rainfall. The trend in average precipitation is positive and significant in 9 of 21 locations and in the region averaged overall. The trend in rainfall variance is positive and significant only in Portland, Albany and Buffalo and insignificant elsewhere and not in the regional average. The trend in daily maximum precipitation is positive and significant only in Portland ME and Gardiner ME and insignificant elsewhere and not in the regional average.]~~

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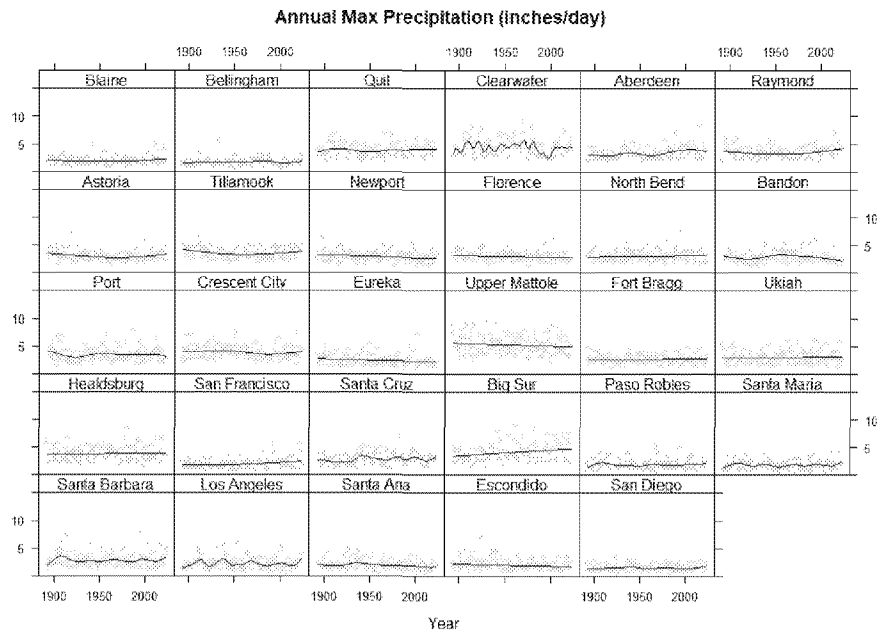


Figure 8.11 Annual maximum precipitation for 29 Pacific stations 1893 to present

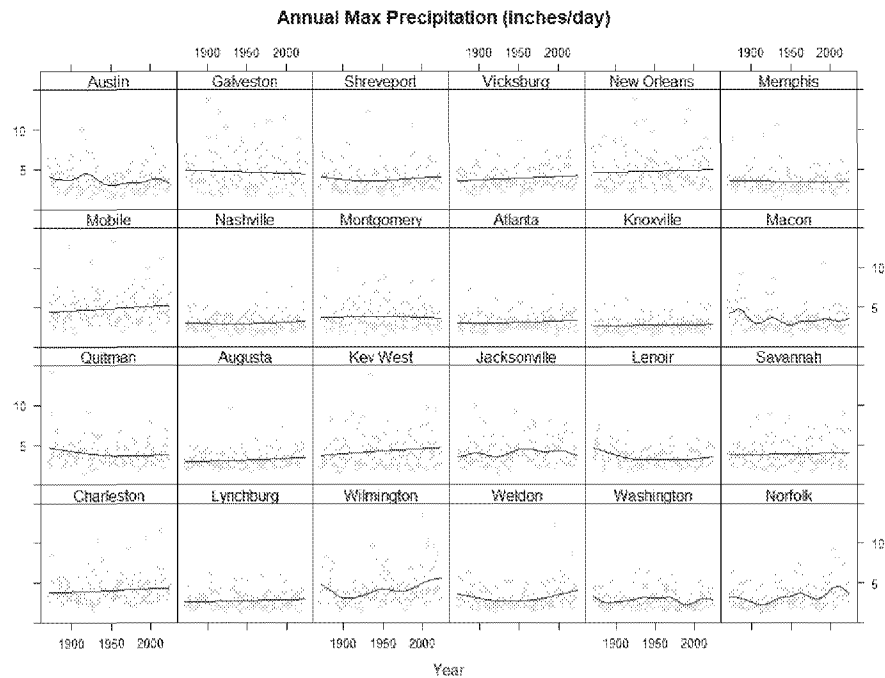


Figure 8.12 Annual maximum precipitation for 24 Southeast stations 1872 to present

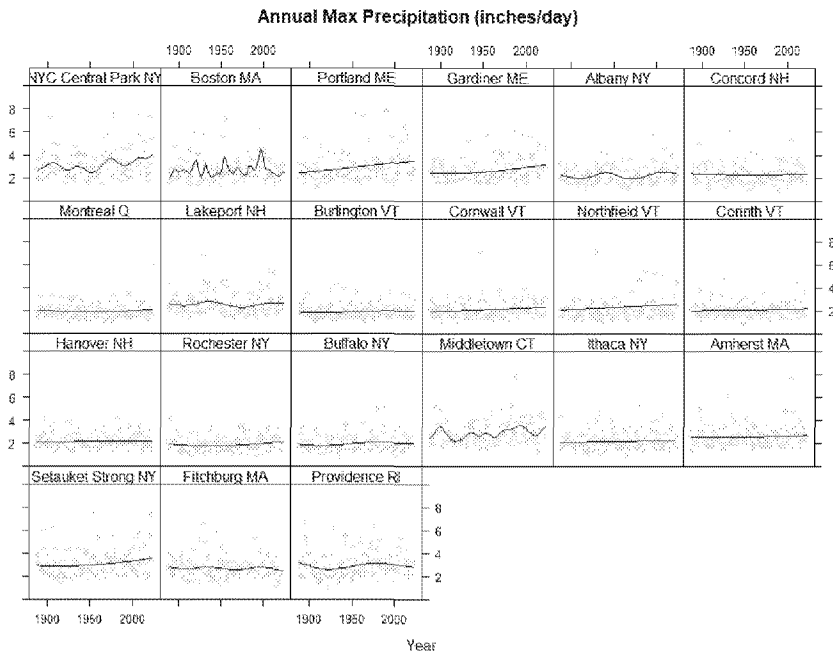


Figure 8.13 Annual maximum precipitation for 21 Northeast stations 1888 to present

Pacific Coast heavy rainfall events

The Pacific Coast receives considerable amounts of precipitation from Atmospheric River (AR) events which often last more than a day or two (e.g., Gershunov et al. 2017, Pan et al. 2024). The worst known such event in recent history was the ArkStorm that occurred between December 1861 and January 1862, which dumped nearly 10 feet of rain in parts of California and submerged the entire Central Valley for weeks under as much as 15 feet of water (Brewer 1930, Null and Hulbert 2007). Paleoclimate research has found six megastorms more severe than 1861–1862 in California during the last 1800 years, occurring at intervals of 300 years or so (Porter et al. 2011).

SIDEBAR: Perils of short data records

San Francisco provides a good case study of the limitation of using short historical samples to characterize natural variability of extreme events. Suppose we use a 130-year sample of daily San Francisco precipitation from 1895 to 2024 and we look for 3-day, 5-day, 14-day and 30-day rainfall records. The results are as shown in Table 8.12.

Event	Record (inches)	Year
3-day	6.94	2023
5-day	8.55	2023
14-day	12.62	2023

30-day 18.93 1998
Table 8.12: Extreme rainfall records, San Francisco, 1895-2024.

The records all cluster in the more recent data. 2023 appears to be an exceptional year and since it is near the end of the sample it would ~~might~~ point to the possibility ~~suggest~~ that the climate has shifted into a potentially more hazardous state, ~~perhaps as a result of human influences.~~

But the picture is very different if we use a sample that begins ~~45 years earlier, in 1850~~. If we extend the record back to 1850 the picture changes. Table 8.23 shows that the record-setting events ~~then~~ all happened in the 1860s. Furthermore 2023 is now not even in 2nd place but falls to 3rd or 4th. Also, comparing the records of the two charts the extreme precipitation events in 1862 and 1867 involved considerably more rainfall than the 1998 and 2023 events, with 14- and 30-day totals about 50 percent higher.

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Event	Record (inches)	Year	Rank of 130-yr extreme
3-day	8.85	1867	3
5-day	9.80	1867	3
14-day	19.05	1862	4
30-day	28.25	1862	2

Table 8.23: Extreme rainfall records, San Francisco, 1850-2024.

~~The~~ The characterization of the range of natural variability is made even more remarkable when paleoclimate evidence is examined. Porter et al. (2011) discovered that in the past 1,800 years at least six megastorms were more intense than the devastating 1861-62 ArkStorm ~~that struck the region~~. Thus, ~~Evidently~~ such extreme events have impacted the region about every 300 years, though not since 1895.

This example illustrates the limitations of using relatively short climate periods (~130 years) to assess the character and range of natural variability in general and of extreme events in particular. Accurate representation of the full range of natural variability is necessary for any attribution analyses (see 6.4). Infrastructure planners, emergency management institutions and attribution scientists would understand the significant mischaracterization of the magnitude of a future extreme if based only on the last 130 years. In this case, a single time-sample of 130 years provides an underestimation of the extreme value by up to 50% determined when adding only 45 more years of observations. Compared to millennial-scale paleoclimate evidence, an even greater underestimation would occur. ~~An important lesson is that the climate can deliver great surprises on its own, even without human influences.~~

We examine occurrences of 5-day deluges as follows. In a 130-year span there are 26 5-year intervals. At each location we computed the 5-day precipitation totals throughout the year and selected the 26 highest values. A single year may have more than one of the 26 heaviest. Each of those can be thought of as 1-in-5yr events. If there are no trends in precipitation then the total number of these events across all stations should be evenly spread out on an annual basis ~~over the years~~. In Fig. 8.14 ~~4.5~~ we show the distribution in time of these events. The deluges associated with the massive 1997-98 El Niño event are readily apparent. While erratic, as is typical of these types of precipitation metrics, there is no indication of a tendency to become more frequent over time.

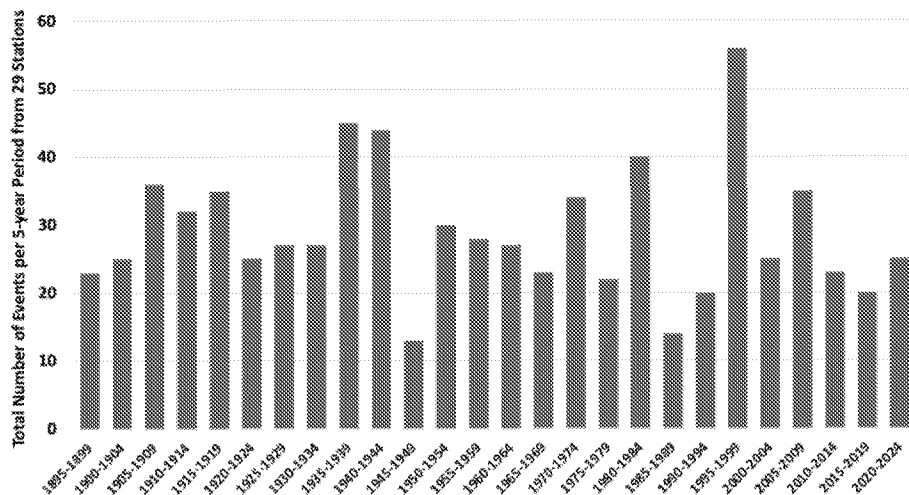


Figure 8.144.5 The time distribution by 5-year periods of the 26-heaviest occurrences for each station (i.e., nominal 1-in-5 year event).

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Southeast heavy rainfall events

The temporal pattern of 5-day totals of the 1-in-5yr heavy events in the humid Southeast (Figure 8.154.6) is generally unremarkable, though a cluster of higher values appears in 1995 to 2019. The increase in those years is due largely to the 4 northeastern-most stations of Wilmington NC, Weldon NC, Washington DC, and Norfolk VA. This confirms the pattern indicated in NCA4 and NCA5 of a tendency for an increasing frequency of heavy events, due to a temporal clustering of tropical storms from eastern NC to Maine discussed below. Otherwise, the remaining 20 stations show an unremarkable temporal distribution of heavy events.

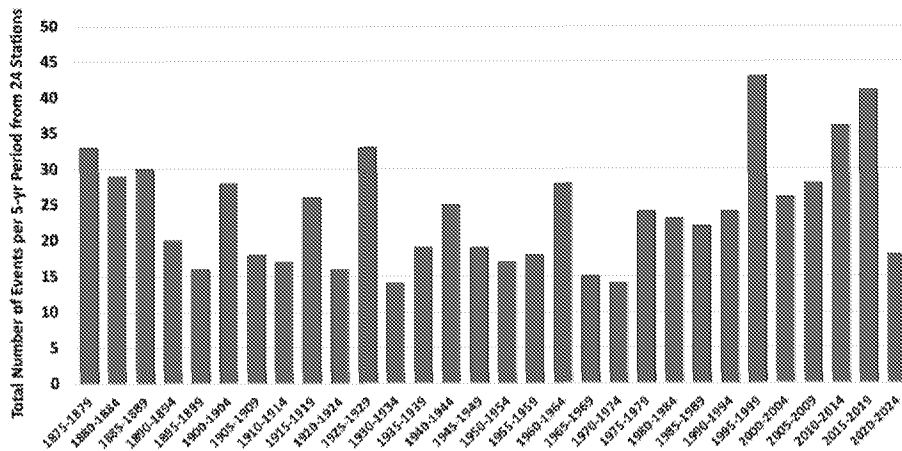


Figure 8.154.6. As above but for the 30 heaviest 1-in-5yr events for 24 stations in the humid Southeast from Austin TX to Washington DC in 5-year bins for 1875-2024.

Northwest heavy rainfall events

Fig. 8.164.7 shows the 27 (1-in-5yr) heaviest 3-day events for the last 135 years in 21 stations in the Northeast (including Montreal Canada). We use 3-day totals here as this produced the largest variations in time. In this region, 72% of the events occur during June to October and are dominated by tropical incursions of hurricanes, tropical storms or tropical storms that transition to extratropical systems. According to NCA4 and NCA5 this region experienced the largest increases in extreme events, so it shall be examined more closely.

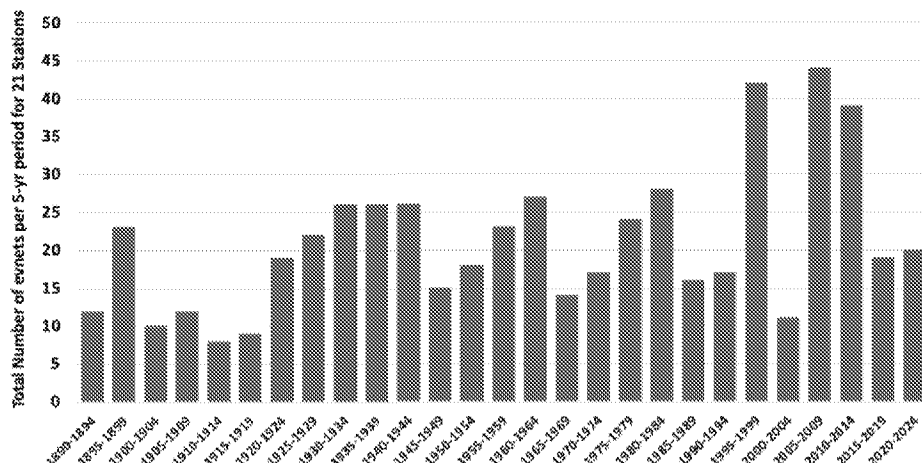


Figure 8.164.7. Time distribution of the heaviest 27 (1-in-5yr) heaviest 3-day precipitation events for 21 stations from NY to ME, including Montreal.

Howarth et al. (2019) report differences in the Northeast between two 18-year periods: 1979-96 and 1997-2014 (a similar region as in Fig. 8.16 that includes PA and NJ) of various precipitation extremes. One metric which indicated a dramatic increase (317%) was found for 24-hr events > 6 inches. This high increase is due to the very small numbers of such events of which there were only 6 in the first period and 25 in the second as reported for 58 stations. This high percentage increase is due to the very small numbers of the events; only 6 in the first period and 25 in the second. Most of the stations did not record such an event suggesting these erratic, episodic events over brief, 18-yr periods, need scrutiny by additional statistical methods.

Using the information in Fig. 8.16 4.7, over the same years as Howarth et al. we find a 51% increase in the frequency of heavy events between the two periods. One can see in Fig. 8.16 that it was unfortunate that Howarth et al. ended in 2014 prior to a return to the long-term average of such events.

A feature of Howarth et al. is the use of single day totals which is questionable because extreme events are often spread across the time of observation boundary. Thus stations measuring at 0700 LT versus those at Midnight will have differing results for a particular event which would then have major impacts on counting these events. We use the 3-day totals in Fig. 8.16 4.7 to be sure to capture the extent of these extreme downpours. In any case, we can confirm that the period 1997 to 2014 experienced a cluster of heavier events as Howarth et al. have documented.

Howarth's most remarkable claim (317% increase in 6" days) is potentially misleading because it is a threshold statistic (see Section 8.34.2 above) and a ratio of small numbers over a short period. The result is not representative of *relative* extreme events for the whole region since the majority of stations never experienced a 6" total. Fig. 8.16 above determines the same number of events for each station (27 heaviest events) whose heaviest values ranged from 4.4" to 12.5" and their 27th heaviest values ranged from 3.3" to 5.0". This analysis thus allows each station to be equally represented. In

other words, if there is a region-wide increase in heavy events, it should be seen in the sum of all stations. Note too that the period of record here is 135 years vs. 36 years of Howarth et al. Except for three 5-year periods between 1995 and 2014 there is nothing statistically remarkable about the results in Fig. 8.164.7.

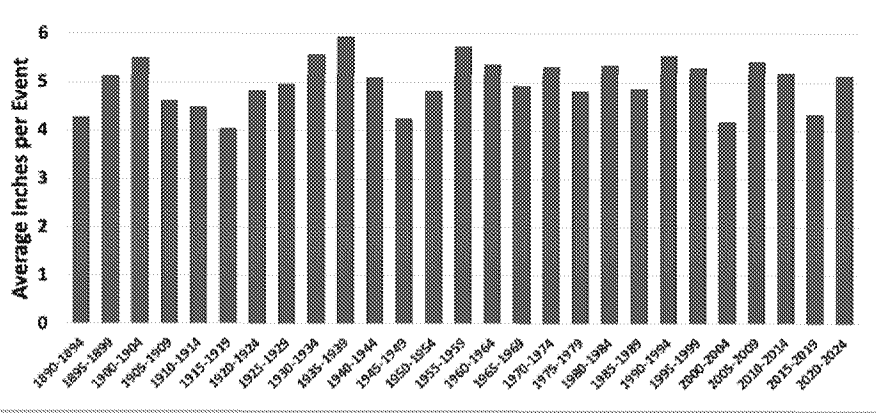


Figure 8.174.8. Average amount of precipitation falling in the 1-in-5yr events for the NE stations.

An interesting aspect of Northeast precipitation is that there has been no change in the amount of precipitation per heaviest event, as shown in Fig. 8.174.8. The trend is only +0.02"/decade. The highest amount, 1935-39, includes the Great New England Hurricane of 1938, one of the rare major (Category 3 or higher) hurricanes to strike the region. The results in Figs. 8.4.615 and 8.16.4.7 suggest that though there was an uptick in the number of events during the period 1995 to 2014, the events, individually, are not becoming more intense.

Jong et al. (2024) document the increase of tropical influences on precipitation events in the Northeast since 1959 and concluded, "The autumn extreme precipitation trend over the Northeast US is primarily attributed to tropical cyclone-related events since the 1990s." The question then becomes, was the temporal clustering of tropical systems in 1997-2014 which affected the Northeast a response to increasing GHGs? Jong et al. examined CMIP-6 model output which suggests that there will be fewer such systems in the 21st century but that the intensity of the rainfall events might increase. This conjecture is not seen in Fig. 8.17 where the amount per event has remained steady over the 135-year period.

For substantial urban areas there is some evidence to indicate the heaviest rainfall events may be redistributed due to the impact urban infrastructure has on the local weather (e.g., Pielke Sr. et al. 2011, Zhang et al. 2018, Yang et al. 2024). Yang et al. state, "Cities that experience compact development tend to witness larger increases in extreme rainfall frequency over downtown than their rural surroundings, while the anomalies in extreme rainfall frequency diminish for cities with

dispersed development." While this is an important insight to consider, the effect on the specific stations used in this analysis is unknown, or at least not detectable in Fig. 8.17.

In summary, the evidence from the historical record of extreme precipitation events in the CONUS is generally not consistent from region to region so that inferences regarding trends and their projections are wrought with significant uncertainty. In most regions and perhaps all, it is our opinion that the very nature of the erratic and episodic character of extreme precipitation events renders the discovery of statistically significant changes, including a relationship to CO₂ concentrations, a result yet to be achieved (McKittrick and Christy 2019).

8.4510 Summary

To be inserted

Based on the content provided in the document, here are the five most important takeaways:

- Limited Detection of Anthropogenic Signals: The IPCC has asserted high confidence in detecting an anthropogenic signal in only 4 out of 34 weather impact categories, and medium confidence in 4 more. For the remaining 26 categories, no anthropogenic signal is claimed to be detected.
- Slow Emergence of Trends: Even under the most extreme forcing scenario (RCP8.5), the IPCC expects very few anthropogenic trends to emerge within this century for most weather impacts.
- Natural Variability Dominance: Natural variability continues to dominate patterns of extreme weather systems. Simple assertions of trend detection are often complicated by regional heterogeneity and trend reversals over time.
- RCP8.5 Scenario Implausibility: The document notes that the RCP8.5 scenario is described as an implausible high-end storyline, not a "base case" or "business-as-usual" projection.
- Conflicting Messages on Attribution: The document mentions that AR6 (IPCC Sixth Assessment Report) offers conflicting messages about the attribution of extreme weather to anthropogenic causes, highlighting the complexity and uncertainty in this area of climate science.

These takeaways emphasize the nuanced and complex nature of attributing extreme weather events to climate change, and the importance of considering natural variability and uncertainty in climate projections.

Commented [A18]: Out of curiosity (and perhaps utility), I fed the entire document (absent this section) into Anthropic's Claude-3.5-sonnet LLM and asked it what are the five most important takeaways. This is what it produced. I'd judge it not a bad start that will need some human improvement, which I'll undertake on the next iteration.

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Appendix: Review of IPCC and NCA Findings on Extreme Weather

The sources we review will be denoted as follows:

SREX: The IPCC *Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* (2012)

AR5: The IPCC *Fifth Assessment Report Working Group 1* (2013).

AR6: The IPCC *Sixth Assessment Report Working Group 1* (2021).

NCA17: The *US Climate Science Special Report of the Fourth National Climate Assessment* (2017) Volume I Chapter 6.

8A.1 Overview: IPCC Assessment of signal emergence in extreme weather types (AR6 WG1 Table 12.12)

Table 8A.1 reproduces the findings of AR6 Table 12.12 which indicates, for 34 major weather event and impact types, whether a signal of anthropogenic forcing has been detected in the historical record (column 1), whether such a signal is likely to emerge by 2050 under the extreme RCP8.5 scenario (column 2) and whether it is likely to emerge by 2100 under RCP8.5 forcing (column 3). It should be borne in mind that the latter two columns suffer from the deficiencies of GCMs discussed in Chapter XX. And as we discussed in Ch X on attribution, AR6 offers three conflicting messages within the AR6 regarding about attribution of extreme weather. Nevertheless, we provide This Table is provided here for reference.

Several patterns stand out. First, detection of an anthropogenic signal is asserted with *high confidence* in only four out of the 34 weather impact categories an anthropogenic signal is asserted with *high confidence* in only four, and with *medium confidence* in a further four. For the rest The IPCC does not *NOT* claim to have detected an anthropogenic signal in the remaining 26 categories. drivers. Of the four *high confidence* assertions, two are for changes in average temperatures (air and ocean), which hence are not measures of extreme weather. Also two Further, two of the four *medium confidence* assertions are related to ocean chemistry and thus are likewise also not related to extreme weather. The IPCC does not *NOT* assert a detectable human influence on many non-temperature weather features such as wind, precipitation, flooding, and drought, etc.

Second, as shown in, columns 2 and 3 show that the IPCC expects very few such anthropogenic trends signals to emerge within this century, even under the most extreme forcing scenario. As we discuss in Section 4.2 the RCP8.5 scenario is an implausible high-end storyline, it is not a “base case” or “business-as-usual” projection. Yet even still Even so, most weather impacts are not expected to exhibit show an anthropogenic signal this century. As will be clear from the underlying report text, nNatural variability dominates patterns of extreme weather systems and simplistic assertions of trend detection are frequently undermined by regional heterogeneity and trends reversals over time.

Climate Impact Driver Type	Climate Impact Driver Category	Already Emerged in the Historical Record?	Emerging by 2050 in Most Extreme CO ₂ Emissions Scenario?	Emerging by 2100 in Most Extreme CO ₂ Emissions Scenario?
Heat & Cold	Average air temperature	YES in most regions	YES	YES
	More heat extremes	YES in most regions	YES in land regions	YES
	Fewer cold extremes	YES in a few regions	YES in many regions	YES
	Less frost	NO	NO	NO

Wet & Dry	Average precip. (Increase or Decrease)	NO	YES (incr) YES (decr)	YES (incr) YES (decr)
	River flooding	NO	NO	NO
	Heavy precip. & pluvial flood	NO	NO	YES in a few regions
	Landslide	NO	NO	NO
	Aridity	NO	NO	NO
	Hydrologic Drought	NO	NO	NO
	Agricultural & ecological drought	NO	NO	NO
Wind	Fire weather	NO	NO	NO
	Average wind speed	NO	NO	NO
	Severe wind storm	NO	NO	NO
	Tropical cyclone	NO	NO	NO
Snow and Ice	Sand and dust storm	NO	NO	NO
	Snow, glacier & ice sheet	NO	YES in a few regions	YES Arctic snow
	Permafrost	YES	YES	YES
	Lake & river ice	NO	YES	YES
	Arctic sea ice	YES	YES	YES
	Antarctic sea ice	NO	YES	YES
	Heavy snowfall and ice storm	NO	NO	NO
	Hail	NO	NO	NO
	Snow avalanche	NO	NO	NO
	Relative sea level	NO	YES	YES
Coastal	Coastal flood	NO	NO	NO
	Coastal erosion	NO	NO	NO
	Average ocean temperature	YES	YES	YES
Open Ocean	Marine heat wave	NO	NO	NO
	Ocean acidity	NO	YES	YES
	Ocean salinity	YES	YES	YES
	Dissolved oxygen	YES (Pacific & S. Ocean)	YES	YES
Other	Air pollution weather	NO	NO	NO

9 Uncertainties in Climate Change Attribution

9.1 Introduction

The Intergovernmental Panel on Climate Change (IPCC) distinguishes between detection of climate change and attribution of its cause.¹ As defined by the IPCC AR6 WGI Glossary (IPCC, 2025):

Detection: “Detection of change is defined as the process of demonstrating that climate or a system affected by climate has changed in some defined statistical sense, without providing a reason for that change. An identified change is detected in observations if its likelihood of occurrence by chance due to internal variability alone is determined to be small, for example, <10%.”

Attribution: “Attribution is defined as the process of evaluating the relative contributions of multiple causal factors to a change or event with a formal assessment of confidence.”

Both steps rely on statistical analysis. Detection focuses on whether changes are significant enough to stand out from random variation regardless of cause. Attribution involves comparison of observed events to model-generated counterfactuals. Since experimentation on the climate is not possible, attribution requires statistical inference to assess how much human activities, such as GHG emissions, versus natural factors, like volcanic eruptions, contribute to observed changes. Attribution methods assume all external and internal drivers of the system are known and represented.

There are ongoing scientific debates around attribution methods, especially for attributing extreme weather events to climate change. The IPCC has long cautioned that methods to establish causality in climate science are inherently uncertain and ultimately depend on expert judgement. The Fourth Assessment Report: The Physical Science Basis (Hegerl et al., 2007) explained it as follows:

‘Attribution’ of causes of climate change is the process of establishing the most likely causes for the detected change with some defined level of confidence... unequivocal attribution would require controlled experimentation with the climate system. Since that is not possible, in practice attribution of anthropogenic climate change is understood to mean demonstration that a detected change is ‘consistent with the estimated responses to the given combination of anthropogenic and natural forcing’ and ‘not consistent with alternative, physically plausible explanations of recent climate change that exclude important elements of the given combination of forcings’ (IPCC, 2001)... The approaches used in detection and attribution research described above cannot fully account for all uncertainties, and thus ultimately expert judgement is required to give a calibrated assessment of whether a specific cause is responsible for a given climate change.

¹ Note that the IPCC definition of “climate change” allows for both natural and human causes. This differs from the [[HYPERLINK "https://unfccc.int/resource/ccsites/zim/bab/conven/text/art01.htm"](https://unfccc.int/resource/ccsites/zim/bab/conven/text/art01.htm)] (and common usage), where the term is limited to human causes.

The Fifth Assessment Report Working Group II makes the following statement:
(Cramer et al., 2014):

“Two broad challenges to the detection and attribution of climate change impacts relate to observations and process understanding. On the observational side, high-quality, long-term data relating to natural and human systems and the multiple factors affecting them are rare. In addition, the detection and attribution of climate change impacts requires an understanding of the processes by which climate change, in conjunction with other factors, may affect the system in question.”

3000 1

Because of the complexity of the causal chains in the climate system, investigation of these relationships is exceptionally challenging.

9.2 Attribution methods

The Intergovernmental Panel on Climate Change (IPCC) employs several attribution methods to assess the causes of observed climate changes, distinguishing between natural and human-induced factors. Below is a concise description of the key methods that have been used by the IPCC:

Optimal Fingerprinting uses linear regression to explain variations in observed climate data as a weighted sum of climate model simulations run with and without anthropogenic forcings. The data used in the regression model are weighted to try to minimize the influence of random noise and the estimation method is chosen to take account of climate model error.

Time Series Analysis exploits statistical differences between anthropogenic forcing and natural variability to see which dominates observed temperatures, and also uses variations in the timing of changes to determine if causal dependence across data series can be inferred.

Process-Based Attribution focuses on understanding the physical mechanisms behind observed changes. This approach combines observations, climate models, and theoretical understanding to attribute changes in specific processes to forcings. This approach is often used for regional climate phenomena, such as monsoon changes or polar amplification

Extreme Event Attribution assesses the role of human influence in the likelihood of occurrence or intensity of extreme weather events (e.g. heat waves, droughts). Methods include:

- Probabilistic Event Attribution uses large ensembles of climate model simulations to compare observed events to model-generated counterfactuals
- Storyline Approach examines the physical processes driving an event and evaluates how anthropogenic forcings may have modified those processes

9.3 Attribution of global warming

Attribution statements for global warming in the three most recent IPCC Assessment reports are:

AR4: “Most of the observed increase in global average temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic greenhouse gas concentrations.” (IPCC, 2007)

AR5: “It is *extremely likely* that more than half of the observed increase in global average surface temperature from 1951 to 2010 was caused by the anthropogenic increase in greenhouse gas concentrations and other anthropogenic forcings together. The best estimate of the human-induced contribution to warming is similar to the observed warming over this period.” (IPCC, 2013)

AR6: “The *likely* range of total human-caused global surface temperature increase from 1850–1900 to 2010–2019 is 0.8°C to 1.3°C, with a best estimate of 1.07°C. It is *likely* that well-mixed GHGs contributed a warming of 1.0°C to 2.0°C, other human drivers (principally aerosols) contributed a cooling of 0.0°C to 0.8°C, natural drivers changed global surface temperature by –0.1°C to +0.1°C, and internal variability changed it by –0.2°C to +0.2°C. It is *very likely* that well-mixed GHGs were the main driver of tropospheric warming since 1979.” (IPCC, 2021)

The AR4 and AR5 attribution statements reference the warming since the mid-20th century, the period when greenhouse gas emissions began rapidly increasing. The words “most” and “more than half” are deliberately imprecise, potentially ranging from 51 to 99% of the warming – presumably this imprecision is to account for structural uncertainties such as natural internal variability. The confidence level increases from *very likely* to *extremely likely* from AR4 to AR5. The structure of the attribution statement in the AR6 is fundamentally different, referencing the warming to the period 1850–1900. The AR6 attribution statement is more precise numerically, but with a lower level of confidence at “likely” – the AR6 attributes essentially all the warming to increases in greenhouse gases. The most confident statement from the AR6 relates to the tropospheric warming since 1979, using the words “main driver” and “*very likely*.”

There are three areas of substantive criticism of the IPCC’s assessment of the causes of the recent warming: inadequate assessment of natural climate variability, inappropriate statistical methods, and substantial discrepancies between models and observations. The last is discussed in Chapter 6, while this chapter discusses the first two factors. All of these criticisms are relevant to the IPCC’s policy-informing attribution of the recent warming, which also underpins extreme event attribution

9.3.1 Natural climate variability

IPCC AR6 states that natural external drivers since 1850–1900 have changed global surface temperature by –0.1°C to +0.1°C, and internal variability has changed it by –0.2°C to +0.2°C – on average having essentially no net impact on the warming since 1850–1900. This minimal contribution of natural variability has been disputed by a number of publications that question the magnitudes of solar variability and internal variability from the large-scale ocean circulations (R Connolly et al., 2021; W Soon, 2023).

If the Equilibrium Climate Sensitivity to CO₂ is low (Chapter 5), then natural climate variability becomes more important in the attribution of the recent warming. Further, if natural variability is higher, then estimates of the Equilibrium Climate Sensitivity from the historical period would be lower (Scafetta, 2023).

Solar variability

IPCC AR5 concluded that the best estimate of radiative forcing due to Total Solar Irradiance (TSI) changes over the period 1750–2011 was 0.05 W/m² (Myrhe et al., 2014). IPCC AR6 acknowledges a much larger range of estimates of changes in TSI over the last several centuries, stating that the TSI between the Maunder Minimum (1645–1715) and the second half of the twentieth century increased by 0.7–2.7 W/m², a range that includes both low and high variability TSI data sets (Gulev, 2021). However, the recommended forcing dataset for the CMIP6 climate model simulations used in AR6 for attribution studies averages two data sets with low solar variability (Matthes, 2017).

While AR6 shows a substantially greater solar impact than does AR5, the overall impact on the climate was assessed to be small compared to anthropogenic forcing of climate change. However, the impact of solar variations on the climate is uncertain and subject to substantial debate — something that is not evident from the IPCC assessment reports (Lockwood, 2012; Connolly et al., 2021).

Exactly how TSI has changed over time has been a challenging problem to resolve. Since 1978, there have been direct measurements of TSI from satellites. However, the data exhibit non-negligible inconsistencies, and interpreting any multi-decadal trends in TSI requires comparisons of observations from overlapping satellites. There are several rival composite TSI datasets, disagreeing as to whether TSI increased or decreased during the period 1986–96 (the ACRIM gap; see Chapter 4). Further, the satellite record of TSI is used for calibrating proxy models, whereby past solar variations are inferred from sunspots and cosmogenic isotope measurements (Velasco Herrera et al., 2015).

There is substantial evidence for high solar activity in the second half of the 20th century (starting in 1959) and extending into the 1990's, before a decline in the early 21st century; this period is often termed the “Modern Maximum.” (Chatzistergos et al., 2023; Solanki et al., 2004; Usoskin et al., 2007). However, some scientists have concluded that it is not possible to be confident of any multi-decadal trend in TSI (Schmutz, 2021).

As a result of this uncertainty, some reconstructions for past values of TSI (since 1750) have low variability, implying a very low impact of solar variations on global mean surface temperature, whereas datasets with high TSI variability can explain more than 70% percent of the temperature variability since preindustrial times (Scafetta, 2013; Stefani, 2021). Hence, the choice of which TSI satellite record used in an analysis can substantially influence how much climate change is attributed to human versus natural forcings.

There is growing evidence that other aspects of solar variability, which are referred to as solar indirect effects, amplify TSI forcing or are independent of TSI forcing. Scafetta et al. (2023) suggests that ~80% of solar influence on climate may stem from non-TSI mechanisms. Candidate

processes include: solar ultraviolet changes; energetic particle precipitation; atmospheric-electric-field effect on cloud cover; cloud changes produced by solar-modulated galactic cosmic rays; large relative changes in the magnetic field; and the strength of the solar wind. Solar indirect effects are not included in climate models, although indirect methods of estimating these effects suggest significant influence. However, claims of non-TSI mechanisms influencing climate are uncertain and debated.

Natural variability of large-scale ocean circulations

Variations in global mean surface temperature are linked to recurrent large-scale variations in ocean circulation patterns. These circulation patterns include the Atlantic Multidecadal Oscillation (AMO), the Pacific Decadal Oscillation (PDO) and the El Niño-Southern Oscillation (ENSO). These circulation patterns influence ocean heat uptake and heat distribution, and also influence atmospheric circulation patterns and cloud distributions. There is some debate as to whether these variations are strictly internal to the climate system, or whether this variability can have a solar/astronomical origin or can be influenced by large volcanic eruptions.

While climate models simulate the large-scale ocean circulations and internal climate variability, the simulated magnitude in the multi-decadal band is too low in most models relative to observations, and the phasing of the variability in long-term climate simulations is not synced with the actual, observed climate variations (Kravtsov et al. 2024). Averaging multiple simulations from climate models effectively averages out the internal variations, leaving only the forced climate variability (e.g., CO₂ forcing). With most of the modern warming beginning in the late 1970's, the recent 50-year warming is on the same time scale as the multi-decadal oscillations of the AMO and PDO.

Here are summary statements from the IPCC AR5 and AR6 reports:

“Decadal variability in the Pacific, associated with the PDO or IPO, contributes significantly to regional and global temperature trends, but the relative contributions of internal variability and external forcing are difficult to disentangle in CMIP5 simulations.” (IPCC, 2013)

“Since AR5, there has been increased understanding of the role of internal variability, such as ENSO, PDO, and AMO, in modulating regional climate trends. However, limitations in simulating the exact timing and amplitude of these modes in CMIP6 models contribute to uncertainties in attributing observed changes to anthropogenic forcing (high confidence).” (IPCC, 2021)

The amplitude of the peak-to-trough impact of the multi-decadal oscillations on global temperatures has been assessed by the IPCC AR6: “The likely range of change due to internal variability is -0.2°C to +0.2°C (IPCC, 2021).” This implies a trough-to-peak change of 0.4°C. Over many centuries, any global temperature changes from the troughs and peaks will cancel out, with little to no net impact.

However, with a nominal timescale of 60-80 years for oscillations such as the AMO and PDO, the timing of the peaks and troughs can be confused with the secular trend. This becomes very relevant

for attributing the warming for the 50 years since 1975, during which most of the warming has occurred. Even if climate models have the correct amplitude of the multidecadal oscillations, the timing of the peaks and troughs is not adequately simulated, with each model and individual ensemble simulating a different phasing. Once the simulations of the ensemble members and different models are averaged, the natural internal variability contribution is averaged out, effectively cancelling the role of natural internal variability in the attribution process.

The Great Pacific Climate Shift of 1976-1977 was a notable climatic event characterized by an abrupt change in the North Pacific Ocean's atmosphere-ocean system that interacted with global climate patterns. This shift is closely associated with the Pacific Decadal Oscillation (PDO) that oscillates between warm and cool phases over decades. The 1976 shift marked a transition from a predominantly negative (cool) PDO phase (1947-1976) to a positive (warm) phase (1977 through 2000), with significant implications for global and regional climate patterns including the frequencies of El Niño and La Niña events. The Great Pacific Climate Shift coincided with the beginning of a period of accelerated global warming (REF TO A FIG OF GLOBAL TEMP ANOMALIES ELSEWHERE IN DOC) When the Great Pacific Climate Shift is accounted for in climate attribution analyses since 1950, it has been found that 40 percent or more of the warming in the second half of the 20th century was caused by natural internal variability (McLean et al., 2009; Tung and Zhou, 2013; Chylek et al., 2016; Scafetta, 2021).

9.3.2 Optimal fingerprinting

Optimal fingerprinting is a statistical technique introduced by Allen and Tett (1999) that compares observed climate data to climate model simulations to identify patterns (or "fingerprints") associated with human or natural forcing. It involves taking a vector of observed climate changes, such as warming rates in locations around the world, and decomposing them into a weighted sum of "signals", which are analogues to the observations generated by climate models with different types of forcings. The weights are chosen using a regression method called Total Least Squares. The analysis commonly uses just two signals, one generated by models using only anthropogenic forcings and one using only natural forcings. If the estimated weighting coefficient attached to a signal is significantly different from zero, then that signal is said to be "detected". If it is close to 1.0, then the model generating the signal is said to be consistent with observations. If it is less than 1.0, then the model signal for that forcing is too strong and needs to be scaled down, and vice-versa. Both the observed data and the signals are weighted using a model-generated estimate of patterns of randomness in the climate system so as, in principle, to put maximum weight on regions where natural variability is minimized.

Optimal fingerprinting is the primary tool for attribution in the climate literature. Studies applying it have been cited thousands of times, and it has been prominently featured by the IPCC since the 2001 Third Assessment Report. One of its inherent weaknesses is that results depend on assumptions about the accuracy of climate models, especially regarding their representation of natural variability (IPCC AR5 Ch 10.2.3).

Additionally, a series of papers by McKittrick (McKittrick 2022a, 2022b, 2023, 2025) has challenged the optimal fingerprinting method, arguing that it is inherently unreliable and that commonly used practices in econometrics can provide more valid results. Statistical theory

requires that for regression models to yield unbiased coefficients, a set of assumptions called the Gauss-Markov conditions must hold. McKittrick (2022a) argued that the Allen and Tett (1999) methodology violates the Gauss-Markov conditions, leading to potentially biased and inconsistent fingerprinting coefficients, undermining the reliability of the method. Chen et al (2023) confirmed this analysis and argued that the method could yield unbiased results but only under very stringent assumptions. McKittrick (2022b) and (2023) raised a further concern that climate scientists—virtually alone among scientific disciplines—have used an estimation method called Total Least Squares (TLS) to estimate anthropogenic greenhouse gas signal coefficients, despite its tendency to be unreliable unless some strong assumptions hold that in practice are unlikely to be true. Under conditions which easily arise in optimal fingerprinting, TLS yields estimates with large positive biases. Thus, any study that has used TLS for optimal fingerprinting without verifying that it is appropriate in the specific data context has likely overstated the result.

McKittrick (2025) presented an empirical example comparing the results of conventional optimal fingerprinting against methods drawn from mainstream econometrics which are known to be valid for the specific application of signal detection. While the IPCC optimal fingerprinting method yields an anthropogenic signal coefficient close to 1.0 on a global temperature data set spanning 1900 to 2010, consistent estimation yields a coefficient around 0.4, which rises to about 0.65 on data spanning 1980 to 2010, implying the model response to greenhouse gases needs to be scaled down by about half to optimally match observations. The natural forcing signal coefficient, by contrast, is between 2.0 and 4.0, implying the climate model signals of natural forcing need to be scaled up two-to-four-fold to match observed climate change. The fingerprinting coefficients estimated in McKittrick (2025), when used to scale the average sensitivity of the climate models used to generate the forcing signals in his data set, imply a Transient Climate Sensitivity of 1.4°C, which matches the estimate by Lewis (2022) using a different estimation method and multiple independent data sets.

While these analyses do not prove that all of the results from using the IPCC optimal fingerprinting method are wrong, it does show that the basis on which they were believed to be correct is non-existent – hence reducing confidence in the results.

9.3.3 Time series methods

The IPCC (AR5 WGI 10.2.2) drew attention to alternative approaches of assessing causality that emerged from the time series econometrics literature. They have the advantage of not depending on assumptions about the accuracy of climate models, but their disadvantage is they depend on assumptions about the data generating process underlying climate and forcing data that are not straightforward to test. The methods, now referred to as climate econometrics, use the tools of unit root testing, Granger causality and cointegration analysis, all of which are familiar in economics and finance and which are slowly being adopted in climate science. Time series analysis methods hold out the possibility of determining whether anthropogenic or natural forcings are the primary drivers of climate change without requiring the use of climate models, although key questions remain unsettled (e.g. Dergiades et al. 2016, Balcombe et al. 2019, Dagsvik et al. 2020, Razzak 2022, Dagsvik and Moen 2023).

Granger causality modeling is a tool for determining directions of influence in data series that move together. “Granger causality” is a statistical, not a physical, concept. If knowing the current

value of one variable significantly improves the forecast accuracy of another variable we can infer a causal connection exists; this is called Granger causality. The modeling tools, called vector autoregression, measure direct impulse-response patterns and feedbacks. An application to the well-known Vostok ice core data revealed an error by Al Gore in his documentary *An Inconvenient Truth*. Gore showed the data and drew attention to the coherence of temperature and CO₂ changes over a 440,000 year span, which he asserted was due to CO₂ driving temperature changes. But temperature changes can also affect atmospheric CO₂ levels. Davidson et al. (2015) examined the series and found that temperature Granger causes CO₂ but not the reverse. In other words on the time scales represented in the Vostok data the coherence in the series is primarily due to the influence of temperature on CO₂ levels not the feedback going from CO₂ to temperature.

In summary, the main statistical methods for attributing causation in climate data are optimal fingerprinting and time series analysis. Applications of the Allen and Tett (1999) optimal fingerprinting method dominate the attribution literature and have underpinned past IPCC conclusions, but results depend on the accuracy of climate models and the method has recently been criticized as inherently biased. Time series methods do not depend on climate models but require assumptions of their own and have generated results that have thus far not converged on a consensus.

9.4 Attribution of climate impact drivers

The IPCC (Ranasinghe et al. 2021) defines “climate impact drivers” or CIDs as “physical climate system conditions (e.g., means, events, extremes) that affect an element of society or ecosystems.” Hence CIDs are those features of the weather and climate system of primary interest when assessing the impacts of climate change since they potentially affect humans and the natural world. For instance, under the heading “Heat and Cold” CIDs are identified as mean air temperature, extreme heat, cold spells and frost. The IPCC also points out that CIDs are not necessarily harm-related: depending on the system in question they can be detrimental, neutral, beneficial or a combination.

Table 12.12 in Ranasinghe et al. (2021, p. 1856) summarizes the AR6 assessment of whether a signal of attributable anthropogenic influence has emerged across all major CIDs. One of the themes of this chapter is that attribution methods used by the IPCC tend to overstate the anthropogenic influence and understate the role of natural variability. Nonetheless a striking feature of that summary table is how few CIDs exhibit an anthropogenic signal sufficient to distinguish them from natural variability. The reported findings are listed in Table 9.1 which adapts IPCC AR6 Table 12.12.²

Climate Impact Driver Type	Climate Impact Driver Category	Already Emerged in the Historical Record?	Emerging by 2050 in Most Extreme CO2 Emissions Scenario?	Emerging by 2100 in Most Extreme CO2 Emissions Scenario?
Heat & Cold	Average air temperature	YES in most regions	YES	YES

² We have separated polar sea ice into Arctic and Antarctic categories for clarity, and removed ground-level CO₂ as a CID since claiming anthropogenic signal due to CO₂ emissions is a tautology.

	More heat extremes	YES in most regions	YES in land regions	YES
	Fewer cold extremes	YES in a few regions	YES in many regions	YES
	Less frost	NO	NO	NO
Wet & Dry	Average Precip. (Increase or Decrease)	NO	YES (incr) YES (decr)	YES (incr) YES (decr)
	River flooding	NO	NO	NO
	Heavy precip & pluvial flood	NO	NO	YES in a few regions
	Landslide	NO	NO	NO
	Aridity	NO	NO	NO
	Hydrologic Drought	NO	NO	NO
	Agricultural & ecological drought	NO	NO	NO
	Fire weather	NO	NO	NO
Wind	Average wind speed	NO	NO	NO
	Severe wind storm	NO	NO	NO
	Tropical cyclone	NO	NO	NO
	Sand and dust storm	NO	NO	NO
Snow and Ice	Snow glacier & ice sheet	NO	YES in a few regions	YES Arctic snow
	Permafrost	YES	YES	YES
	Lake & river ice	NO	YES	YES
	Arctic sea ice	YES	YES	YES
	Antarctic sea ice	NO	YES	YES
	Heavy snowfall and ice storm	NO	NO	NO
	Hail	NO	NO	NO
	Snow avalanche	NO	NO	NO
Coastal	Relative sea level	NO	YES	YES
	Coastal flood	NO	NO	NO
	Coastal erosion	NO	NO	NO
Open Ocean	Average ocean temperature	YES	YES	YES
	Marine heat wave	NO	NO	NO
	Ocean acidity	NO	YES	YES
	Ocean salinity	YES	YES	YES
	Dissolved oxygen	YES (Pacific & S. Ocean)	YES	YES
Other	Air pollution weather	NO	NO	NO
	Solar or IR radiation at surface	NO	NO	NO

Table 9.1. IPCC AR6 summary of the probable emergence of an anthropogenic signal above natural climate variability for all global or regional “climate impact drivers” (CIDs) of concern for humans and ecosystems in response to increasing atmospheric greenhouse gas concentrations (primarily CO₂). Source: Table adapted from report of Working Group I, Table 12.12). Red = high confidence; yellow = medium confidence; green = no anthropogenic signal detectable above natural variability (50% confidence).

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Several patterns stand out. First, out of the 34 weather impact categories an anthropogenic signal is asserted with *high confidence* in only four, and with *medium confidence* in a further four. For the rest the IPCC does not claim to have detected anthropogenic drivers. Of the four *high confidence assertions*, two are for changes in average temperatures (air and ocean) hence are not measures of extreme weather. Also two of the four *medium confidence assertions* are related to ocean chemistry and thus are likewise not related to extreme weather. The IPCC does not assert a human influence on many non-temperature weather features such as wind, precipitation, flooding, drought etc.

Second, as shown in columns 2 and 3 the IPCC expects very few such signals to emerge this century even under the most extreme forcing scenario. As we discuss in Chapter 4 the RCP8.5 scenario is an implausible high-end storyline, it is not a “base case” or business-as-usual projection. Yet even still most weather impacts are not expected to exhibit an anthropogenic signal this century. As we discussed in Chapter 7 natural variability dominates patterns of extreme weather systems and simplistic assertions of trend detection are frequently undermined by regional heterogeneity and trend reversals over time.

A point we emphasized in Chapter 7 was that, despite commonly-heard claims that all types of extreme weather are getting worse due to human activity, few significant trends in most weather types can be detected due to high levels of natural variability over long time scales. Table 9.1 makes the related point that, again contrary to popular belief, attribution of changes in most extreme weather types to human influence is not currently possible. Taking wind as an example, the IPCC claims that an anthropogenic signal has not emerged in average wind speeds, severe windstorms, tropical cyclones or sand and dust storms, nor is one expected to emerge this century even under an extreme emissions scenario. The same applies to drought and fire weather.

9.5 Extreme event attribution (EEA)

Examining the IPCC’s treatment of extreme weather and climate event attribution more broadly, the AR6 provides an ambiguous assessment of the role of anthropogenic warming that differs between chapters. Chapter 11 of WG1 states (Seneviratne et al., 2021):

“Evidence of observed changes in extremes and their attribution to human influence (including greenhouse gas and aerosol emissions and land-use changes) has strengthened since AR5, in particular for extreme precipitation, droughts, tropical cyclones and compound extremes (including dry/hot events and fire weather). Some recent hot extreme events would have been extremely unlikely to occur without human influence on the climate system.”

By contrast, as noted, Chapter 12 of WG1 (Table 2.12) paints a different picture – presumably, the expert judgment of different groups of authors for the two chapters came to different conclusions (Ranasinghe, 2021):

- High confidence in an increase in extreme heat events in tropical regions where observations allow trend estimation and in most regions in the mid-latitudes, medium confidence elsewhere
- Medium confidence in a decrease in extreme cold events in Australia, Africa and most of northern South America where observations allow trend estimation
- No evidence of emergence in the historical period of a change in river floods, heavy precipitation, drought, fire weather, severe wind storms, and tropical cyclones

While the overall issue of detecting changes in extreme weather events and their attribution remains ambiguous, most of the activity in this area relates to the attribution of single extreme weather events. The most prominent effort is the World Weather Attribution (WWA; worldweatherattribution.org), which is an international research initiative that focuses on extreme event attribution analyzing how climate change influences the likelihood and intensity of extreme weather events. The approach used by the WWA runs large ensembles of regional climate models

to compare the event in today's climate, versus a pre-industrial counterfactual climate without human-caused warming.

WWA plays a prominent role in linking extreme weather to climate change and its press releases attract considerable public and policy discussions. However, the WWA's tendency to promote non-peer-reviewed findings, funding ties, open admission that they shape their analyses to serve purposes of litigation and other methodological challenges have sparked controversies, with critics questioning the robustness and impartiality of its conclusions (Pielke Jr. 2024). Despite these issues, WWA's work continues to shape climate science and media narratives. Technical criticisms of the approach include: neglect of a formal detection process; an implicit assumption that 100% of the post-industrial warming is caused by CO₂; and failure to adequately account for natural internal climate variability.

Because EEA is relatively new many basic methodological issues have yet to be settled in the expert literature. An important challenge is the lack of data. Extreme events are by definition rare. Many analyses of extreme event types (including the US National Assessment Reports) only evaluate data since 1950 or 1970. However, as emphasized by Chapter 7, many of the worst extreme weather and climate events in U.S. history occurred prior to the first half of the 20th century including in the early 19th century. And if paleoclimate reconstructions are considered, it becomes very difficult for an event to pass the detection thresholds of exceeding what is expected from natural variability, particularly if a reasonably sized geographic region is considered.

Another challenge is defining the event under study. There is a longstanding literature in statistics and econometrics on the challenge of analyzing data with outliers. The issue arises because a data series establishes a probability distribution defining the expected range of observations. If an outlier is observed it might indicate that the underlying process giving rise to the data distribution has changed (which in the weather context would mean a climatic change has been detected) or that the underlying process has multiple regimes each with a different probability distribution, in which case observing an outlier simply means we were temporarily in a different regime, but the system itself was unchanged. If a time series contains only a single outlier event at the end of the series it is not possible to determine which model is the correct one (Chen and Liu 1993). For instance, there might be an "ordinary" weather regime that yields a distribution of summer daytime highs in a particular coastal region, and a second "heatwave" regime that kicks in when an inland blocking event occurs, which yields a temperature distribution centered 15°C higher than the first one. A day with temperatures 13°C above normal would either be an extreme heat anomaly under the first regime or a somewhat cool event under the second, and we have no way in this case of knowing on statistical grounds which view is correct.

Visser and Petersen (2012) and Sardeshmukh et al. (2015) both point out that different distributions may fit observed data equally well but yield very different implications about the likelihood of a specific weather event. Visser and Petersen argue that, in view of the deep uncertainties of extreme weather analysis drawing a connection between individual events and global climate change should be avoided. Furthermore the existence of an outlier at the end of a data series poses the problem that estimates of the event probabilities will be biased whether the outlier is included or excluded (Barlow et al. 2020). Methods to eliminate the bias have not yet been established, leading some experts (e.g. Miralles and Davison 2023) to argue that in settings in which a data series

contains a single extreme event at the end, estimation of a return period for the extreme event will be so biased and uncertain it should be avoided altogether.

In spite of these concerns, the U.S. is presently considering something like the WWA, which is being investigated by a NASEM Panel on Attribution of Extreme Weather and Climate Events and their impacts (NASEM, 2025).

A case study from a recent high impact extreme events in the U.S. is provided to illustrate the challenges and ambiguities in attributing the frequency and intensity of extreme weather events to human-caused warming.

9.4.1 Case study – 2021 Western North America heat wave

The 2021 Western North America heat wave was an extreme heat wave that affected much of Western North America in late June 2021. In particular, surface temperature records were set in Portland, OR (116°F; previous record 107°F) and Seattle, WA (108 °F; previous record 103°F) (Mass et al., 2024).

The WWA team garnered international headlines for their analysis and provided the following attribution statements (WWA, 2021; Philip et al., 2022):

- Based on observations and modeling, the occurrence of this heatwave was virtually impossible without human-caused climate change.
- The event is estimated to be about a 1 in 1000-year event in today's climate.
- The event would have been at least 150 times rarer without human-induced climate change.
- This heatwave was about 2°C hotter than it would have been if it had occurred at the beginning of the industrial revolution (when global mean temperatures were 1.2°C cooler than today).

But an important caveat to the first claim is that other researchers concluded, based on historical weather data, that while a heat wave of the magnitude observed was indeed virtually impossible without anthropogenic climate change, it was also virtually impossible *with* climate change. Bercos-Hickey (2022) noted “these temperatures were virtually impossible under any previously experienced meteorological conditions, with or without global warming.” McKinnon and Simpson (2022) stated “the most likely explanation remains that the weather event itself was ‘bad luck.’” The 2023 Oregon Climate Assessment (Fleischman 2023) concluded that the heat dome would have formed even without climate change and “There is no evidence that the highly unusual combination of weather features that drove the heat dome were made more likely by climate change, and climate models do not project an increase in the frequency of high-pressure ridges over the Pacific Northwest” (Fleischman 2023 p. 49).

Mass et al (2024) summarizes the proximate sequence of compound events leading to the heat wave. There was a record-breaking midtropospheric ridge over the Pacific Northwest, forced by a tropical disturbance in the western Pacific. This produced record-breaking midtropospheric temperatures, strong subsidence in the lower atmosphere, low-level easterly flow that produced downslope warming on regional terrain and the removal of cooler marine air, and an approaching

low-level trough that enhanced downslope flow. The event occurred at a time of maximum solar insolation, and drier-than-normal soil moisture. Using a storyline approach, Mass et al. assessed that there is no trend in drought and dry soils in the Pacific Northwest; there is no evidence of global warming producing stronger ridges of high pressure, and no observed trend in heat waves or record temperatures in the region. They concluded that although anthropogenic warming may have contributed as much as 2°F to the magnitude of the event, there is little evidence of further amplification of the event from increasing greenhouse gases.

A statistical analysis of a model-based attribution study of this heat wave was conducted by Bercos-Hickey et al. (2022). Because this event is a far outlier and far above the bounds of Generalized Extreme Value distributions fitted from historical data, they concluded that estimates of return times, quantitative changes in event magnitude and frequency, and probability of the extreme temperatures such as provided by the WWA are not accurate and should be interpreted as having low confidence. They found that hindcast attribution methods using an ensemble of regional climate models, combined with Pearl (2009) causal inferences, can provide limited and conditional information about the magnitude of the human influence on this heatwave – they provided a more highly constrained estimate that human activities caused a ~1.4°C–1.8°F increase in the daily maximum temperatures.

Zeder et al. (2023) also concluded that the methods employed by Philip et al. (2022) tend to overstate the rarity of extreme heat waves, leading to a biased perception of the effect of climate change on the heatwave event: “The tendency to overestimate the return period of observed extreme heatwave events may fuel the impression that seemingly impossible heatwave extremes are currently clustering at an unprecedented rate.”

The 2021 Western North America heatwave was a rare and unprecedented compound weather event, that broke century-old temperature records by as much as 9°F. While the WWA team received worldwide publicity for their rapid attribution claims blaming anthropogenic climate change, subsequent peer-reviewed analysis showed that the rare event was not made more probable by global warming.

9.5 Summary

There is an ongoing scientific debate around attribution methods, particularly in attributing extreme weather events to climate change. The IPCC has long cautioned that methods to establish causality in climate science are inherently uncertain and ultimately depend on expert judgement.

There are two areas of substantive criticism of the IPCC assessment of the causes of the recent warming: inadequate assessment of natural climate variability, and inappropriate statistical methods.

Detection of extreme weather events is challenged by their rarity, requiring a long data set and a choice of region and spatial scale to evaluate their occurrence against the background of natural weather and climate variability.

The most robust attribution statements for an extreme event relate to an incremental change (e.g. a temperature change in degrees or percent change in rainfall). Statements related to return times, quantitative changes in event magnitude and frequency, and probability of the extremes are not accurate owing to an inadequate amount of data, and are made with low confidence. There is no evidence in a change of weather or climate regime patterns from increasing greenhouse gases that would amplify or dampen extreme weather events, beyond basic thermodynamic considerations.

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11. Managing risks of extreme weather

Notions of “dangerous climate change” relate to climate change risk. The IPCC defines climate change risk as the dynamic association of the three core elements of risk: hazard, exposure, and vulnerability. Hazard captures the frequency and intensity of extreme weather and climate events or slowly emerging change such as sea level rise. Exposure refers to the elements of population, infrastructures, and social welfare at risk. Vulnerability refers to the exposures’ potential to suffer as well as its ability to manage, withstand and rebound. Risks from human-caused climate change are convoluted with natural weather and climate variability, and are dominated by the exposure of wealth in coastal and other disaster-prone regions and vulnerabilities of poorer populations.

11.1 Socioeconomic context

Risks from human-caused climate change are convoluted with natural weather and climate variability, and are dominated by the exposure of wealth in coastal and other disaster-prone regions and vulnerabilities of poorer populations. The evolution of climate risk in the U.S. has been dominated by societal factors, rather than by changes to the actual weather and climate hazards. Deaths from weather disasters have decreased substantially since 1900, even as US population grew from 76 million in 1900 to over 331 million in 2020. For example, the Galveston hurricane killed over 8,000 people in 1900 (0.01% of the US population), whereas the worst recent disaster, Hurricane Katrina in 2005, killed 1800 people (or 0.0006% of the US population).

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Technological advances have substantially reduced losses from extreme weather events. Early warning systems, satellite monitoring, and improved weather forecasting have reduced deaths, although exactly numbers are hard to quantify. [HYPERLINK "https://www.nber.org/papers/W3135/"]

US weather forecasting has been estimated to reduce losses from weather events with an annualized benefit of \$31.5B, protecting lives, property, and supporting agriculture and transportation. [HYPERLINK "https://nap.nationalacademies.org/read/12888/chapter/2"] Improved hurricane forecasts have reduced pre- and post-landfall spending, with annual per hurricane cost reductions estimated at \$5B. [HYPERLINK "https://www.noaa.gov/stories/2024/09/04/09-04-improving-hurricane-forecasts"]

Infrastructure improvements have contributed to substantial reductions in losses from extreme weather events. Building codes, such as those implemented in Florida after Hurricane Andrew (1992) have reduced losses by ensuring structures can withstand high winds and floods. Homes built after 2002 showed minimal damage during Hurricane Michael (2018), unlike older homes. [HYPERLINK "https://www.fema.gov/case-study/role-floridas-building-codes-2018-hurricane-michael"]. Sea walls, like the Galveston Seawall, protect against wave action and storm surge. The New Orleans Hurricane and Storm Damage Risk Reduction System successfully mitigated storm surge during Hurricane Isaac (2012). Inland dams in the US help control flooding by storing excess water during heavy rains. It is estimated that the Tennessee Valley Authority (TVA) dams prevent about \$309M in annual flood damage in the TVA region and along the Ohio and Mississippi Rivers. [HYPERLINK "https://www.tva.com/environment/managing-the-river/flood-management"]

During Hurricane Helene (2024), TVA’s strategies prevented approximately \$406M in potential

damages. [HYPERLINK "https://www.publicpower.org/periodical/article/tva-flood-mitigation-strategies-prevented-approximately-406-million-potential-damages"]

11.2 Data challenges

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Since 1980, NOAA has provided a count of annual U.S. weather-related disasters that it estimates to have exceeded \$1Billion (inflation adjusted), showing a substantial increase starting in 2008. NOAA and other government officials have cited the upward trend in the BDD series as evidence that climate change is making extreme weather worse (Pielke Jr. 2024). Over time, population and wealth have increased dramatically in the US, so that when an extreme weather or climate event occurs, there is more damage even if there is no underlying trend in the frequency or intensity of extreme weather. A recent estimate finds that losses per weather disaster are down by about 80% since 1980, as a proportion of GDP.

Pielke Jr. (2024) argued that in addition to relying on opaque data sources and unreported adjustments NOAA failed to normalize its Billion Dollar Disaster (BDD) data series properly for By adjusting for inflation, but not for changes in population exposure and wealth or vulnerability. In May 2025 NOAA announced it has withdrawn the billion dollar disaster product from publication (Pielke Jr. 2025). the NOAA billion dollar data set reflects the growth in population and wealth, which swamps any changes in actual weather hazards. While absolute losses from weather and climate disasters have grown, they are a smaller fraction of GDP today, reflecting economic growth outpacing disaster-related costs.

Technological advances have substantially reduced losses from extreme weather events. Early warning systems, satellite monitoring, and improved weather forecasting have reduced deaths, although exact numbers are hard to quantify. [HYPERLINK "https://www.noaa.gov/papers/3135/"] US weather forecasting has been estimated to reduce losses from weather events with an annualized benefit of \$3.5B, protecting lives, property, and supporting agriculture and transportation. [HYPERLINK "https://nap.nationalacademies.org/read/12888/chapter/2"] Improved hurricane forecasts have reduced pre- and post-landfall spending, with annual per hurricane cost reductions estimated at \$5B.

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During Hurricane Helene (2024), TVA's strategies prevented approximately \$406M in potential damages. [HYPERLINK "https://www.publicpower.org/periodical/article/tva-flood-mitigation-strategies-prevented-approximately-406-million-potential-damages"]

In summary, trends in losses from extreme weather and climate events are dominated by population increases and economic growth. Technological advances such as improved weather forecasting and early warning systems have substantially reduced losses from extreme weather events. Better building codes, flood defenses, and disaster response mechanisms have lowered economic losses relative to GDP. And finally, the US economy's expansion has diluted the relative impact of disaster costs, as seen in the comparison of historical and modern GDP percentages.

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13 Climate change and the economy

13.1 Climate change and economic growth

13.1.1 Overview: climate is a relatively minor issue for a modern economy

It has long been noted that economies tend to do poorly in very cold and very hot regions, with the optimum somewhere in between (Nordhaus 2006). Temperature-sensitive economic activity migrates, whenever possible, to where it is best suited, and in all cases people adapt to the local climate in which they live. Based in part on these observations, in 1992 Thomas Schelling, then President of the American Economic Association, argued that whatever effects climate change would have on US economic activity they would be small relative to the many other changes that would happen.

... Manufacturing rarely depends on climate, and where temperature and humidity used to make a difference, air conditioning has intervened. When Toyota chooses among Ohio, Alabama, and Southern California for locating an automobile assembly, geographical considerations are important, but not because of climate... Finance is little affected by climate; similarly for health care, or education, or broadcasting. Transportation can be affected, but improvements in all-weather landing and take-off in the last 30 years are greater than any differences that climate makes. If the average effect is a warming, iced waterways and snow removal may decline in importance. Construction is affected, mainly by cold, and if the average effect is in the direction of warming, construction may benefit slightly.

It is really agriculture that is affected. But even if agricultural productivity declined by a third over the next half century, the per capita GNP we might have achieved by 2050 we would achieve only in 2051. ...

I conclude that in the United States, and probably Japan, Western Europe, and other developed countries, the impact on economic output will be negligible and unlikely to be noticed.

(Schelling 1992, emphasis added)

Thirty years later virtually the identical point was made by the IPCC itself in the Fifth Assessment Report:

For most economic sectors, the impact of climate change will be small relative to the impacts of other drivers. Changes in population, age, income, technology, relative prices, lifestyle, regulation, governance, and many other aspects of socioeconomic development will have an impact on the supply and demand of economic goods and services that is large relative to the impact of climate change.

(Arent et al. 2014, emphasis added)

While extreme weather events are costly, in all modern economies they are becoming steadily less and less important (Formetta and Feyen 2019). Since 1990 weather-related disaster losses have declined as a proportion of global GDP (Pielke Jr 2018, 2020) as have mortality risks (Formetta and Feyen 2019). While economic weather-related insurance payouts are rising, this is fully explained by the growth in the size of the economy and the value of the insured asset stock. Past increases in episodes extreme weather have not had a significant effect (positive or negative) on the market

value of insurance firms (Hu and McKittrick 2015). Nor have past extreme weather events had a significant effect on US banks' performance (Blickle et al. 2021).

In view of all these things economists have long been reluctant to endorse attempts to "stop" climate change or even aggressively reduce GHG emissions because the costs would not be worth it. As one critic of the economics of climate policy put it:

Mainstream climate economics takes global warming seriously, but perplexingly concludes that the optimal economic policy is to almost do nothing about it... The contrast is striking. While climate science is sending out loud-and-clear messages that fossil-fuel disinvestment must start now, letting go of coal and oil and diverting resources into renewable energy technology systems, to keep warming below the 2°C limit (IPCC 2014), mainstream climate economics claims that overly ambitious climate targets will unnecessarily hurt the economy and immediate de-carbonization is too expensive. Most climate economists thus recommend humanity to just wait-and-see.
(Storm 2017)

The mainstream economics position on the climate policy question is best represented by the findings over the past three decades from the use of Integrated Assessment Models (IAMs) of climate change policy, for which Yale economist William Nordhaus was awarded the 2018 Nobel Memorial Prize in economics. IAMs combine economic, climate, and social data into a unified framework for simulating climate damages and evaluating the optimal policy response (Resources for the Future 2025). Nordhaus' work has generally supported modest global climate policy, with aggressive measures largely deferred to later in the century. Nordhaus developed the so-called Dynamic Integrated Model of the Climate and Economy model, or DICE, in the early 1990s (Nordhaus 1993) to study the interaction between climate change, climate policy and global economic growth over long time horizons. DICE assumes global emission control can be coordinated at no cost and asks what the optimal policy target should be. The climate component of the DICE model is based on standard but very simplified climatological modeling concepts. The version of DICE at the time of Nordhaus' Nobel Prize award was described in Nordhaus (2018). His climate sensitivity parameter was 3.1°C for CO₂ doubling, the same as the best estimate in contemporary IPCC reports (3.0°C).

The baseline (no policy) scenario incurs only \$0.4T in abatement costs and leads to \$134.2T (trillion dollars) in climate damages for a total cost of \$134.6T. The climate model component of DICE projects 4.1°C warming by 2100 compared to preindustrial temperatures under this path. Note that this is a higher estimate of warming than many IPCC climate models.

The Optimal Policy scenario barely deviates from the business-as-usual path. It aims for +3.5°C warming, in other words we scale back only the lowest-value fossil fuel use and otherwise just live with almost all the warming. This suggests that most CO₂ emissions are less harmful than the policies that would be necessary to abate them. Trying to prevent warming causes costs quickly to outstrip the benefits. Pursuing a goal of capping warming at 2.5°C creates total costs of \$177.8T, which is \$43.2T worse than doing nothing at all. Nordhaus didn't evaluate trying to reach a Paris-type target of 1.5°C warming but it would be even worse.

A subsequent edition of DICE includes higher assumed damages from warming which not surprisingly leads to more aggressive policy recommendations. This will be explained in the section below on the Social Cost of Carbon.

13.1.2 Empirical analysis of climate change and economic growth

Many other studies have used econometric methods instead of IAMs to look at the potential impact of climate change on economic growth. Dell et al. (2012, herein DJO12) was an influential study that used a multi-country panel of national-level data spanning 1950 to 2005, in which they matched climate and economic data by averaging temperature from the local grid cell level up to the national level using population weights. They found that warming yields an insignificant positive effect on income growth in rich countries but a significant negative effect in poor countries. Moore and Diaz (2015) modified the DICE model to take that finding into account and concluded that it implied a dramatically higher Social Cost of Carbon due to the compounding effects of income loss over time.

A large subsequent literature has debated the robustness of the DJO12 findings. Burke et al. (2015) analyzed a global panel with temperatures averaged up to the national level and found a negative effect on growth from warming in rich and poor countries alike when the national average temperature is above 13°C. Zhao et al. (2018) used the G-Econ data set of Nordhaus (2006), which breaks economic activity down to the grid cell level, replicated DJO12-type results on the same subset of countries as used in DJO12 but then showed that on the full global sample warming increases growth in rich countries and poor countries alike, though the positive effect in the latter group is confined to where local temperatures are below about 16°C. Greßer et al. (2021) developed a regional economic data set for 1,542 sub-national regions around the world between 2005 and 2015 and found no effect of temperature on growth. Yang et al. (2023) updated the DJO12 data set and applied an estimator robust to mixed sample frequencies, finding that while temperature shocks exerted a temporary effect on income levels, they did not have a significant lasting effect on growth rates.

Newell et al. (2021) noted that there is no underlying theory to guide econometric model specification in this literature. Taking into account the arbitrary choices of which explanatory variables to include they identified over 800 possible model specifications. Using the Burke et al. (2015) data they used an estimation method that accounts for model uncertainty and found that the model form preferred by Burke et al. (2015), which implied negative effects of warming on growth even in rich countries, is explicitly excluded by the optimal model selection algorithm. Overall they could not detect a temperature effect on GDP or GDP growth, and they estimated the 95% confidence interval for the impact on global growth as of 2100 even under the exaggerated RCP8.5 warming scenario spans -86 percent to +388 percent. In other words the net effect is likely positive but too uncertain to distinguish from zero.

Barker (2023) criticized the DJO12 assumption that countries can be grouped into fixed “poor” and “rich” categories based on their incomes many decades ago. He noted that many countries were once poor but became rich over time, and if this is taken into account the original temperature effects reported by Dell et al. became small and insignificant.

Berg et al. (2023) argued that countries shouldn't be grouped into large Rich/Poor categories because they are too heterogeneous. They instead estimated country-specific temperature response coefficients then grouped countries with similar response coefficients into small panels. They separately estimated responses to global and idiosyncratic local temperature shocks to better identify the climate signal in weather data. Overall they found countries experiencing negative effects of warming on growth outnumbered those experiencing positive effects, but only temporarily: eventually the effects reverse such that about twice as many countries experience a net positive growth effect. They also found global (as opposed to local) temperature changes are much more likely to benefit growth in poor countries than rich ones. In a simulation to 2100 even using the extreme RCP8.5 scenario they computed the average global GDP loss would be only 1.9%

compared to a scenario with no warming. That is, instead of the economy growing 400% it would grow 398%. The implication of Nordhaus' analysis is that trying to prevent the warming would lead to far less than 398% growth.

To summarize, economists have long considered climate a relatively unimportant factor in economic growth, a view echoed by the IPCC itself in the Fifth Assessment Report. Mainstream climate economics has recognized that CO₂-induced warming may have some negative economic effects but they are too small to justify aggressive abatement policy, and trying to "stop" or cap global warming even at levels well above the Paris target would be worse than doing nothing. An influential study in 2012 suggested that global warming would harm growth in poor countries but it has subsequently been found not to be robust. Studies that take full account of modeling uncertainties either find no evidence of a negative effect on global growth from CO₂ emissions or find poor countries as likely to benefit from it as rich countries.

13.2 Models of the Social Cost of Carbon

The Social Cost of Carbon (SCC) is a tool for understanding the economic impact of carbon dioxide emissions, helping policymakers weigh the costs and benefits of climate policies. It estimates the damage caused by emitting one additional ton of CO₂, expressed in dollars. More formally, the SCC is the discounted present value of the current and future marginal loss of economic welfare due to an additional tonne of CO₂ entering the atmosphere. On its own the SCC is not the appropriate price to attach to CO₂ emissions for the purpose of optimal emissions control but it can be converted into an optimal tax rate by scaling it by the Marginal Cost of Public Funds (MCPF). The theory behind this was first derived by Sandmo (1975) and has been reiterated many times since then by other economists working on the topic (e.g. Parry et al. 1999). The MCPF is the cost in terms of lost private economic welfare of raising public revenue by one dollar and always exceeds unity. If a jurisdiction does not use a carbon tax, this formula still indicates the upper bound on the amount emitters should spend on abatement options at the margin along the optimal policy path. Regulations should be imposed only insofar as they do not impose marginal abatement costs in excess of the optimal tax rate.

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13.1.2 Estimating the SCC

Although the literature refers to "estimates" of the SCC, it is not estimated in the way other economic statistics are estimated. For instance, data on market transactions including prices and quantities can be used to estimate the current inflation rate or the growth rate of per capita real Gross Domestic Product, and there are well-understood uncertainties associated with these quantities. But there are no market data available to measure many if not most of the marginal damages or benefits believed to be associated with CO₂ emissions, so these need to be imputed using economic models.

For example, an influential component of some SCC calculations is the perceived social cost associated with changed risk of future mortality due to extreme weather. There is no market in which people can directly attach a price to that risk. At best economists can try to infer such values by looking at transactions in related markets such as real estate or insurance, but isolating the component of price changes attributable to atmospheric CO₂ levels is very difficult.

Economists use IAMs to compute the SCC. Two of the best known IAMs are the Climate Framework for Uncertainty, Negotiation and Distribution ("FUND", Tol 1997) and Nordaus' DICE. IAMs embed a stylized global climate model with a very simplified representation of the global economy, including

a “damage function” or set of functions relating ambient temperature to local economic conditions. The assumptions embedded in the damage function will largely determine the resulting SCC.

One approach to developing a damage function is to begin with estimates of the costs (or benefits) of warming in specific sectors in countries around the world and aggregate up to a global amount. This was the approach used in FUND. An alternative approach is to develop a simple equation that penalizes global income according to a simple quadratic function of the average global temperature. This approach was used in DICE. In the case of the FUND model many hundreds of parameters had to be selected, whereas in DICE only three were needed and were originally chosen to assign a predetermined penalty (1.2%) to global output as of 3°C warming, with a quadratic term implying that damages grow with the square of the global average temperature anomaly. Barrage and Nordhaus (2024) recently changed the parameters to increase the penalty at 3°C to 1.6%, and added a discrete additional 1.0% GDP penalty at 3°C warming to account for “tipping points” (discrete large-scale environmental changes triggered by crossing a warming threshold) and a “judgmental adjustment” of 0.5% for excluded impacts at 3°C warming. Not surprisingly the newer version of DICE generates much higher SCC estimates than before.

The concepts of estimation and uncertainty do not readily apply to SCC calculations. By comparison, the question of whether precipitation has trended up or down along the South Carolina coast for the past hundred years can be addressed by collecting rainfall data, estimating a trend parameter and calculating statistical confidence intervals using methods with well-understood mathematical properties. In this way uncertainty can, in principle, be resolved by collecting more data and applying more accurate methods. But no amount of data collection can change the fact that many components of the SCC are unknown and rely on judgment and opinion based on knowledge of the underlying literature on the physical effects of climate change.

SCC calculations are thus best thought of as “if-then” statements: *if* the following assumptions hold, *then* the SCC is \$X per tonne. The list of ‘if’ statements includes the premise that the world’s climate and economy work according to the representation in the IAM. One way this may fail to hold is in the timing of warming. Every IAM assumes a value of the Equilibrium Climate Sensitivity (ECS), controls the amount of warming that results from CO₂ emissions and can be freely varied for the purpose of generating a distribution of SCC values associated with uncertainties over ECS. But as Roe and Baumann (2013) pointed out, time-to-equilibrium increases with the square of ECS, so an upward adjustment of the ECS parameter without an appropriate slowing down of the adjustment process can yield distorted present value damage estimates. In particular, the upper tail of warming associated with some commonly-used ECS distributions is physically impossible for even a thousand years into the future (Roe and Baumann 2013) yet in an IAM would be realized within a couple of centuries. Failure to align ECS with time-to-equilibrium will lead to an overestimate of the SCC value.

13.2.2 Variations in the SCC

Every level of the IAM calculation includes assumptions, some more influential than others. Key assumptions include the following

- The discount rate: Climate damages accrue over a long time horizon, and costs a century or two in the future need to be discounted to the present. The higher the discount rate the smaller the present value of future damages and vice versa. The discount rate represents the opportunity cost of spending money today rather than investing it and then having more to spend tomorrow. Some economists have argued for the use of very low discount

rates in SCC calculations, resulting in policy recommendations that favor relatively large immediate investments in CO₂ emission reductions. The downside is that other investments could potentially earn a larger rate of return for society.

- Equilibrium Climate Sensitivity: IAMs have customarily employed a value of 3.0°C or 3.1°C following the IPCC's guidance. Empirically-estimated ECS values tend to be lower than this (see Chapter XX). Dayaratna et al. (2017, 2020, 2023) have shown that use of lower empirically-derived ECS values dramatically lower the resulting SCC estimate, even when low discount rates are used.
- Damage function coefficients: IAMs assume CO₂ and warming cause net harms that increase exponentially with temperature. More recently, IAMs have also incorporated effects from assumed potential climate tipping points. The FUND model took limited but explicit account of CO₂ fertilization effects in agriculture. Since the coefficients were selected prior the publication of the current evidence of global greening and the magnitude of benefits to crops from elevated CO₂ (see Chapters 2 and 10) the growth effects are likely understated. The DICE model (and others) did not explicitly include any CO₂ fertilization benefit, except to the extent it was taken into account in the literature consulted when picking the damage function coefficients. The damage function in FUND contains a region in which low warming yields net benefits in many regions, a finding which is supported by econometric models of warming and growth (Berg et al. 2023) and econometric simulations of agricultural changes (McKittrick 2025). The DICE damage function, by construction, rules out net benefits at any warming level.
- Emission scenarios: IAMs generate SCC estimates that increase as the pre-existing concentration of CO₂ increases. Consequently the value of damages later in the century will be higher, depending on the assumed baseline emissions over the coming decades.
- Abatement costs: IAMs represent the cost to the economy of reducing CO₂ emissions. If CO₂ emission reductions are assumed to be inexpensive, then the model will conclude that the optimal policy should aim for deeper emission cuts and vice versa.

It is informative to ascertain whether SCC results are invariant to changes in some assumptions. But when different assumptions result in higher or lower SCC values, the change in the SCC value does not provide prima facie evidence about the validity of the assumptions. For example, in 2023 the US Environmental Protection Agency raised its preferred SCC value about 5-fold over the estimates it had issued ten years earlier. This is not because new data had been collected or better mathematical methods had been invented, but because new assumptions had been used, and the validity of those assumptions was a separate question. One was that global agricultural damages were far higher than previously assumed, based on an analysis in Moore et al. (2017). But McKittrick (2025) showed that Moore et al. (2017) had used a database in which half the CO₂ change observations were missing. When as many of those observations as possible were recovered from underlying sources and the analysis was rerun, the projected crop yield losses disappeared and turned into gains at all warming levels. Hence the portion of the EPA's SCC revision attributable to agricultural yield losses was unwarranted.

It should also be noted that the SCC is focused on the social costs of CO₂ emissions from fossil fuel use. It does not measure the private marginal benefits to consumers and society from the availability of fossil fuels. Public willingness to pay for fuels of all types indicates the value to society of reliable, abundant fossil energy. Tol (2017) estimates that the private benefit of carbon is

large relative to the social cost. This can be illustrated by noting that the price of a gallon of gas indicates the marginal value to the consumer of the fuel. Suppose we assume a relatively high Social Cost of Carbon of, say, \$75 per tonne. Deflated by a MCPF value of 1.5 that would result in a carbon tax of \$50 per tonne, which equates to about 44 cents per gallon of gas (Lavelle 2019). A pre-tax price of \$3.00 per gallon would imply the marginal social benefit of the fuel is nearly seven times the marginal social cost.

It is increasingly being argued that the SCC is too variable to be useful for policymakers. Cambridge Econometrics (Thoung 2017) stated it's "time to kill it" due to uncertainties. The UK and EU no longer use SCC for policy appraisal, opting for "target-consistent" carbon pricing (UK Department for Energy Security and Net Zero 2022, Dunne 2017). However the weaknesses of the SCC concept don't mean that other regulatory measures are inherently better or more efficient. Many climate regulations (such as electric vehicle mandates, energy efficiency regulations and bans on certain types of home appliances) end up costing far more per tonne of abatement than a simple price on carbon emissions.

In summary, SCC estimates are highly uncertain due to unknowns in future economic growth, socioeconomic pathways, discount rates, climate damages, and system responses. The SCC is not intrinsically informative as to the economic or societal impacts of climate change. It provides an index connecting large networks of assumptions about the climate and the economy to a dollar value. Some assumptions yield a high SCC and others yield a low SCC. The evidence for or against the underlying assumptions needs to be established independently; the resulting SCC adds no additional information about the validity of those assumptions.

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Introduction

This document ~~originated had its origin in an initiative undertaken in late March 2025 when by Secretary Wright to assemble assembled an independent team to write a brief report for him on issues in climate science relevant for energy policymaking, with particular focus on the question of whether carbon dioxide emissions pose a danger to endanger the US public. The team authors of this report agreed on the usefulness of such a document and agreed to undertake the work on the condition that there was to would be no editorial oversight by the Secretary, the Department of Energy or any other government personnel. This condition has been honored throughout the process and the writing team has worked with full independence.~~

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The team began working in early April with a ~~final submission deadline of May 28. Because of the~~ short timeline and the technical nature of the material ~~meant we have not tried to produce that we could not~~ comprehensively review of all topics. While the report is intended to be accessible for non-experts, we ~~deliberately have~~ omitted some introductory or explanatory material that can easily be accessed elsewhere. Nor have we attempted to survey entire literatures related to the topics selected for focus covered. The scientific and technical material herein is just a sample of the only samples vast literature on climate change but is, we believe, more than sufficient to establish our conclusions.

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The team writing this report was not involved in, nor briefed on, any ~~Administration plans or administrative processes related to a potential challenge to the 2009 EPA CO₂ Endangerment Finding. During the writing of this report we received no information about the Administration's plan on that matter. We were asked, however, to include some information related to the role of US motor vehicles in global climate change, since that is an issue of relevance to the Department of Energy.~~

The writing team wishes to express its grateful thanks to Secretary Wright for the opportunity to prepare this report and for his support for independent scientific inquiry.

12 Mortality risks from heat and cold temperature extremes

12.1 Heat and cold risks

Changes in temperature extremes are among the most certain impacts expected in a warming globe -- extreme heat events are expected to become more frequent while extreme cold events become less frequent. This pattern The greatest confidence for impacts from global warming is an increase in extreme heat events and a decrease in extreme cold events; this has been observed is evident in the historical period (as discussed in Section XX) and is also expected to intensify with continued warming.

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Mortality from during heat extremes is typically caused by heat stroke and heat exhaustion, while, m Mortality from during cold extremes is typically caused by hypothermia and heart strain. It is well known that global mortality is substantially greater for extreme cold than for extreme heat.^{1,2}

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Specifically with regards to the Specific to the U.S., extreme heat and extreme cold both kill hundreds of people each year; however, different approaches to assessing heat/cold mortality produces different results. The Center for Disease Control (CDC) National Center for Health Statistics Compressed Mortality Database, which is based on death certificates, indicates that about twice as many people die of "excessive cold" conditions in a given year than of "excessive heat."^{3,4}

A 2015 epidemiological study of deaths in published in *The Lancet* found that cold-related deaths in the U.S. were about a factor of fifteen higher than heat-related deaths.⁵ However, the study did not adjust for the seasonal cycle in mortality rates, which tend to increase during the winter months due to non-weather factors like influenza.⁶ A more recent paper found that 86% of temperature-related deaths in the U.S. are due to cold-related mortality.⁷

¹ Qi Zhao et al., "Global, Regional, and National Burden of Mortality Associated with Non-Optimal Ambient Temperatures from 2000 to 2019: A Three-Stage Modelling Study," *The Lancet Planetary Health* 5, no. 7 (July 2021), [https://doi.org/10.1016/s2542-5196\(21\)00081-4](https://doi.org/10.1016/s2542-5196(21)00081-4).

² <https://ourworldindata.org/part-one-how-many-people-die-from-extreme-temperatures-and-how-could-this-change-in-the-future>

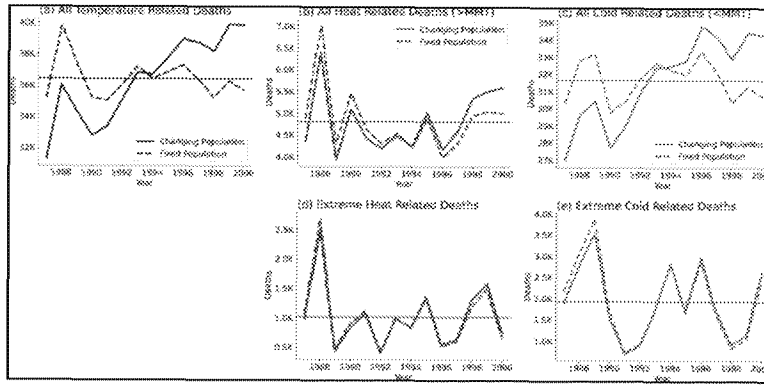
³ Brett R. Scheffers et al., "The Broad Footprint of Climate Change from Genes to Biomes to People," *Science* 354, no. 6313 (November 11, 2016): aaf7671, <https://doi.org/10.1126/science.aaf7671>.

⁴ Rachel H. Alinsky, Scott E. Hadland, J. Deanna Wilson, Pamela A. Matson, and Brendan Sabner, "Trends in Polysubstance Overdose Deaths Involving Opioids, Stimulants, and Benzodiazepines by Race and Ethnicity in the US, 2007-2021," *JAMA Network Open* 7, no. 3 (March 2024): e238249, <https://doi.org/10.1001/jamanetworkopen.2024.8249>.

⁵ Lancet Commission on Climate and Health, "Health and Climate Change: Policy Responses to Protect Public Health," *The Lancet* 386, no. 10006 (November 7, 2015): 1861-1914, [https://doi.org/10.1016/S0140-6736\(15\)60854-6](https://doi.org/10.1016/S0140-6736(15)60854-6).

⁶ Bob Henson, "Which Kills More People: Extreme Heat or Extreme Cold?" *Weather Underground*, January 22, 2019, <https://www.wunderground.com/cat6/Which-Kills-More-People-Extreme-Heat-or-Extreme-Cold>.

⁷ Taik Benmahnia et al., "Deaths Attributable to Heat and Cold: Comparison of Data Sources and Evaluation of Inconsistencies," *GeoHealth* 8, no. 3 (March 2024): e2023GH000799, <https://doi.org/10.1029/2023GH000799>.



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Caption Figure 12.1: Time series of temperature-related deaths across all 106 cities. (a) The solid line represents total temperature-related deaths, while the dashed line indicates temperature-related deaths with a fixed population (average population from the 1987–2000 period). (b) Similar to (a), but for heat-related deaths. (c) Similar to (a), but for cold-related deaths. (d) Time series of deaths occurring in temperatures above the 97.5th percentile. (e) Similar to (d), but for temperatures below the 2.5th percentile. From <https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2023GH000799>

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The IPCC AR6 Working Group 2 Chapter 16.2.3.5 states how heat-related mortality is declining over time:⁸

“Heat-attributable mortality fractions have declined over time in most countries owing to general improvements in health care systems, increasing prevalence of residential air conditioning, and behavioral changes. These factors, which determine the susceptibility of the population to heat, have predominated over the influence of temperature change.”

A 2011 study of 40 major US cities between 1975 and 2004, found that heat wave mortality had decreased, in spite of rising temperatures, due to adaptation.⁹ Likewise Davis et al. (2003) examined heat-related mortality in 28 U.S. cities from the 1960s to the end of the 1990s and found that heat-related mortality declined by three-quarters over the sample period. Bobb et al. (2014) examined mortality data for 106 million people in over 100 cities U.S. cities and found a 60% decline in average heat-related mortality over the period 1987–2005, from 51 per thousand deaths to 19. They furthermore found that the greatest drop was among seniors over the age of 75. In a

⁸ B. O'Neill et al., “Key Risks Across Sectors and Regions,” in *Climate Change 2022: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (Geneva, CH: Intergovernmental Panel on Climate Change 2021), 2411–2538.

⁹ Keith T. Ingram, Carolyn W. Fuman, and John W. Jones, “Climate Change Impact and Adaptation Assessment: A Guide for Coastal Resources Managers,” *Weather, Climate, and Society* 3, no. 4 (October 2011): 234–249, <https://doi.org/10.1175/WCAS-D-11-00055.1>.

study of 42 million deaths in 211 U.S. cities from 1962 to 2006, Nordin et al. (2015) found a more than 90 percent decline in the risk of mortality from excess heat.

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In the context of large declines in heat-related mortality, ~~By~~ **reducing mortality from cold events and adapting to heat extremes, rising temperatures are associated with a net saving of lives.**

It is both disappointing and telling to see how the IPCC misrepresents the situation in its AR6 Synthesis report. Section A.2.5 of that document states: "In all regions increases in extreme heat events have resulted in human mortality and morbidity (*very high confidence*)."¹ But it is silent on the larger decline of deaths during extreme cold events.

12.2 The importance of adaptation

The observed decline in US heat-related mortality has been specifically attributed to adaptation. Wang et al. (2018) exploited the spatial variability of heatwave-related mortality across 209 U.S. cities from 1962 to 2006. While the raw data implies an increase in mortality risk during heatwaves, accounting for adaptation to heatwave intensity caused the effect to fall to near zero and become statistically insignificant. They used the results of their epidemiological model to project heat-related mortality out to 2050 under four RCP warming scenarios (including RCP8.5) with and without adaptive behavior. Assuming people continue to adapt to the heatwave risks in the regions in which they live Wang et al. project not only no increase in heat-related mortality but an overall decrease for the US as a whole. They conclude that "Ignoring adaptation would result in a substantial overestimate of future mortality related to heat waves... Accounting for adaptation, the overall heat-related mortality by 2050 would not change substantially over time compared to 2006."

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Mortality risks and energy costs

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A 2016 study of US long term mortality risks associated with temperature variations (Barreca et al. 2016) showed that increases in mortality across the US are associated both with cold weather and hot weather. But over time, the introduction of electricity and the adoption of central heating and air conditioning (AC) dramatically reduced both risks, especially those associated with hot weather. Prior to 1960, a day above 90°F (32°C) added 2.2 percent to the average mortality risk rate, but after 1960 the same weather added only 0.3 percent to mortality risk, an 85 percent reduction. Prior to 1960 temperatures below 39°F (4°C) added about 1 percent to mortality risk but after 1960 the same weather only added about half that amount. Adaptation through conventional household improvements dramatically reduced public vulnerability to weather extremes. The entire reduction in hot weather mortality was attributable to widespread adoption of indoor AC, which depended on the availability of reliable and affordable electricity.

The corollary of this finding is that the use of heating and cooling systems depends on energy being affordable. Doremus et al. (2022) showed that wealthy and poor households in the US adjust their energy expenditures at similar rates in response to moderate temperature swings, but not in response to extreme temperature swings. When temperatures swing to very cold levels ($< 5^{\circ}\text{C}$) energy spending in high-income households rises by 1.2 percent but in low-income households by only 0.5 percent. On very hot days ($> 30^{\circ}\text{C}$) electricity spending in high-income households rises by 0.5 percent but does not change at all in low-income households. The latter result is observed even in subsamples where all households have AC. The implication is that even with widespread adoption of home heating and cooling systems, inability to afford energy leaves low-income households exposed to weather extremes.

Barreca, Alan, Karen Clay, Olivier Deschenes, Michael Greenstone, and Joseph S. Shapiro. "Adapting to climate change: The remarkable decline in the US temperature mortality relationship over the twentieth century." *Journal of Political Economy*, 2016, 124 (1), 105–159.

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Scenario	Year	Crop demand	Energy crop demand	Livestock demand	Energy crop production	Non-energy crop production
SSP1 - 1.9	2005	3389946625		238986475.6	31469668.7	3417340000
SSP1 - 1.9	2010	3780159000		262440747.1	56039029.3	3813367000
SSP1 - 1.9	2020	4330961000		289096841.8	91136859.74	4354620000
SSP1 - 1.9	2030	4764790750		309853936.5	445930839.8	4944219000
SSP1 - 1.9	2040	5110124250		324523696.3	1574852336	5147676000
SSP1 - 1.9	2050	5455829250		339193526.4	2006291953	5456159000
SSP1 - 1.9	2060	5464465625		332888770.5	2870823938	5464506000
SSP1 - 1.9	2070	5473166625		326584119.1	4050276313	5473212000
SSP1 - 1.9	2080	5481933875		320279377.9	5564746500	5481968000
SSP1 - 1.9	2090	5490764875		313974711.9	6731205375	5490793000
SSP1 - 1.9	2100	5499663000		307670098.6	8014704250	5499687000
SSP1 - 2.6	2005	3389946625		238986475.6	31469668.7	3417340000
SSP1 - 2.6	2010	3780159000		262440747.1	56039029.3	3813367000
SSP1 - 2.6	2020	4330961000		289096841.8	95187658.69	4355897000
SSP1 - 2.6	2030	4764790750		309853936.5	161969332.5	4827157000
SSP1 - 2.6	2040	5110124250		324523696.3	399864022.5	5254736000
SSP1 - 2.6	2050	5455829250		339193526.4	808240431.6	5477702000
SSP1 - 2.6	2060	5464465625		332888770.5	1637018906	5471201000
SSP1 - 2.6	2070	5473166625		326584119.1	2995031625	5479598000
SSP1 - 2.6	2080	5481933875		320279377.9	5202315750	5486188000
SSP1 - 2.6	2090	5490764875		313974711.9	7526928500	5495285000
SSP1 - 2.6	2100	5499663000		307670098.6	7748012625	5509088000
SSP1 - 3.4	2005	3389946625		238986475.6	31469668.7	3417340000
SSP1 - 3.4	2010	3780159000		262440747.1	56039029.3	3813367000
SSP1 - 3.4	2020	4334602375		289174832	109423546.9	4361476000
SSP1 - 3.4	2030	4776535875		310123299.8	215929142.1	4852597000
SSP1 - 3.4	2040	5130602250		324986742.2	421916095.2	5309377000
SSP1 - 3.4	2050	5485054125		339850246.1	758487498	5519592000
SSP1 - 3.4	2060	5494617875		333571646.5	1241709566	5508623000
SSP1 - 3.4	2070	5504243500		327292790	2014145227	5519789000
SSP1 - 3.4	2080	5513932500		321014147.5	3242520125	5529474000
SSP1 - 3.4	2090	5523683375		314735501	6014199125	5538850000
SSP1 - 3.4	2100	5533499500		308456711.9	8482560250	5548808000
SSP1 - 4.5	2005	3389946625		238986475.6	31469668.7	3417340000
SSP1 - 4.5	2010	3780159000		262440747.1	56039029.3	3813367000
SSP1 - 4.5	2020	4339871875		289206884.8	121538069.8	4365692000
SSP1 - 4.5	2030	4789960750		310242688.5	302516750	4833716000

SSP1 - 4.5	2040	5153440375	325304516.6	571864125.5	5291867000
SSP1 - 4.5	2050	5517297625	340366303.7	906001980.5	5544530000
SSP1 - 4.5	2060	5527588625	334133506.8	1308092318	5539393000
SSP1 - 4.5	2070	5537941500	327900635.7	1974305289	5552553000
SSP1 - 4.5	2080	5548358500	321667820.3	2992365000	5566294000
SSP1 - 4.5	2090	5558838000	315435009.8	3964526844	5577937000
SSP1 - 4.5	2100	5569383250	309202231.4	4540259125	5588570000
SSP1 - Bas	2005	3389946625	238986475.6	31469668.7	3417340000
SSP1 - Bas	2010	3780159000	262440747.1	56039029.3	3813367000
SSP1 - Bas	2020	4347582125	289282287.1	122898720.7	4373590000
SSP1 - Bas	2030	4808445875	310456300.8	310195404.3	4849270000
SSP1 - Bas	2040	5181673375	325796189.5	588363849.6	5320158000
SSP1 - Bas	2050	5555269875	341136144.5	906566365.2	5582935000
SSP1 - Bas	2060	5566552250	334972203.1	1233003105	5578910000
SSP1 - Bas	2070	5577899250	328808197.3	1923219180	5594197000
SSP1 - Bas	2080	5589310125	322644175.8	2882637469	5610093000
SSP1 - Bas	2090	5600786875	316480181.6	3780147672	5624206000
SSP1 - Bas	2100	5612326250	310316118.2	3976263906	5635640000
SSP2 - 1.9	2005	2562601266	216129997	0	2734478368
SSP2 - 1.9	2010	2743381807	233117496.4	0	3032884054
SSP2 - 1.9	2020	3240968703	274615831.9	938601454.5	3533324392
SSP2 - 1.9	2030	3680531207	312901169.3	1792971341	3973154860
SSP2 - 1.9	2040	3835749663	320698974.2	3058171341	4128231931
SSP2 - 1.9	2050	3776165098	310942612	4619314897	4068085715
SSP2 - 1.9	2060	3565781095	291049273.4	6366850246	3856034496
SSP2 - 1.9	2070	3431014635	276707794.1	7900094276	3720025280
SSP2 - 1.9	2080	3261283723	261323786.7	9106460399	3549695631
SSP2 - 1.9	2090	3089132872	244389578.4	9954286409	3375412830
SSP2 - 1.9	2100	2903320664	226570798.3	10581315270	3183984473
SSP2 - 2.6	2005	2562601266	216129997	0	2734478368
SSP2 - 2.6	2010	2743381807	233117496.4	0	3032884054
SSP2 - 2.6	2020	3237874875	274382410.3	1026868121	3530230798
SSP2 - 2.6	2030	3721526037	315811043.4	1586571341	4014150642
SSP2 - 2.6	2040	4068857235	345656412.3	2245571341	4361486744
SSP2 - 2.6	2050	4282110196	360684725.3	3073904674	4574683211
SSP2 - 2.6	2060	4330660741	360853169.3	4237971705	4623033265
SSP2 - 2.6	2070	4305793128	357231063.5	5901253250	4597730598
SSP2 - 2.6	2080	4203009592	346840839.2	7654804470	4494383185
SSP2 - 2.6	2090	4023176428	331033307.7	9015083390	4313713465
SSP2 - 2.6	2100	3818645969	314039959.7	9983781970	4107834920
SSP2 - 3.4	2005	2562601266	216129997	0	2734478368
SSP2 - 3.4	2010	2743381807	233117496.4	0	3032884054
SSP2 - 3.4	2020	3246219174	275496711.7	938601454.5	3538613994
SSP2 - 3.4	2030	3739180838	317292079.3	1160838008	4031805506
SSP2 - 3.4	2040	4127857896	350854242.4	1607838008	4420509913
SSP2 - 3.4	2050	4420510815	374643894.9	2344971341	4713160261
SSP2 - 3.4	2060	4578887569	386990181.1	3281704674	4871483411

SSP2 - 3.4	2070	4652700094		392618684.7	4414305039	4945195476
SSP2 - 3.4	2080	4641985423		392091972.9	5942412463	4934266125
SSP2 - 3.4	2090	4517722522		381399372.7	7413937803	4809698138
SSP2 - 3.4	2100	4337699238		365387690.3	8598271136	4628869734
SSP2 - 4.5	2005	2562601266		216129997	0	2734478368
SSP2 - 4.5	2010	2743381807		233117496.4	0	3032884054
SSP2 - 4.5	2020	3248917997		275839084.9	938601454.5	3541323517
SSP2 - 4.5	2030	3745438630		317729576.9	1058571341	4038069092
SSP2 - 4.5	2040	4159658312		352634669	1304838008	4452318462
SSP2 - 4.5	2050	4492174743		380686753.4	1709238008	4784848480
SSP2 - 4.5	2060	4712009911		399023954	2318038008	5004669273
SSP2 - 4.5	2070	4834685184		409914104	3309945797	5127300778
SSP2 - 4.5	2080	4875660229		414819297.5	4596479130	5168194521
SSP2 - 4.5	2090	4818471005		411139333.4	5835726789	5110846865
SSP2 - 4.5	2100	4687290137		401639483.2	6815054091	4979390465
SSP2 - 6.0	2005	2562601266		216129997	0	2734478368
SSP2 - 6.0	2010	2743381807		233117496.4	0	3032884054
SSP2 - 6.0	2020	3251815303		276120344	938601454.5	3544221721
SSP2 - 6.0	2030	3747678810		318008550.7	1029038008	4040308540
SSP2 - 6.0	2040	4176345414		354213553.9	1085571341	4469005322
SSP2 - 6.0	2050	4536363588		383735170.7	1237838008	4829049200
SSP2 - 6.0	2060	4809400776		406764621.9	1790504674	5102106487
SSP2 - 6.0	2070	4986592736		422765346.2	2347505039	5279289678
SSP2 - 6.0	2080	5082883306		432640241.9	2878479130	5375548171
SSP2 - 6.0	2090	5120586811		437128596.9	3357212463	5413196873
SSP2 - 6.0	2100	5070522839		435639160.9	3875204267	5363053826
SSP2 - Bas	2005	2562601266		216129997	0	2734478368
SSP2 - Bas	2010	2743381807		233117496.4	0	3032884054
SSP2 - Bas	2020	3254604910		276592207.6	938601454.5	3547035356
SSP2 - Bas	2030	3748450305		318148911.2	1029038008	4041098202
SSP2 - Bas	2040	4180407480		354609432.5	1085571341	4473086071
SSP2 - Bas	2050	4548648170		384838090.8	1244971341	4841352055
SSP2 - Bas	2060	4836569216		409034747.9	1711838008	5129282933
SSP2 - Bas	2070	5032566591		426433917.4	2294504674	5325285643
SSP2 - Bas	2080	5171049715		439297008.6	2786279130	5463747167
SSP2 - Bas	2090	5265445917		447270074.8	3212612463	5558108145
SSP2 - Bas	2100	5302376806		451089114.2	3580279131	5594997470
SSP3 - 3.4	2005	2274624100	0	246084000	0	3254988500
SSP3 - 3.4	2010	2638405600	207424500	270010500	0	3546514000
SSP3 - 3.4	2020	3346379800	563275100	317845300	23807300	4124060500
SSP3 - 3.4	2030	4555102100	1586371500	355994500	94732000	4733432700
SSP3 - 3.4	2040	9528768500	7402989100	381268700	1071635300	5301054400
SSP3 - 3.4	2050	1.83E+10	17992488300	401796500	3068492000	5786625400
SSP3 - 3.4	2060	2.5394E+10	26523962900	419259500	4661989800	6222629000
SSP3 - 3.4	2070	3.5933E+10	39375695900	434614600	7167183100	6600240800
SSP3 - 3.4	2080	4.2857E+10	47720115000	449019900	8802562900	6930666100
SSP3 - 3.4	2090	4.8456E+10	54416968000	461911900	10140013100	7225136600

SSP3 - 3.4	2100	5.254E+10	59214813000	473973200	11122271200	7506876700
SSP3 - 4.5	2005	2274624100	0	246084000	0	3254988500
SSP3 - 4.5	2010	2638405600	207424500	270010500	0	3546514000
SSP3 - 4.5	2020	3346379800	563275100	317845300	23807300	4124060500
SSP3 - 4.5	2030	4334357800	1308262100	356197800	78865500	4696965700
SSP3 - 4.5	2040	7100780500	4357552800	383253300	569242400	5207008600
SSP3 - 4.5	2050	1.426E+10	12924807400	405031800	2149181000	5708250500
SSP3 - 4.5	2060	2.4894E+10	25872437300	422248000	4568162000	6213920600
SSP3 - 4.5	2070	2.8874E+10	30511765800	439808400	5402502400	6623522300
SSP3 - 4.5	2080	3.4127E+10	36738348000	456706400	6607696600	6984669600
SSP3 - 4.5	2090	3.9657E+10	43321945700	471661200	7938064700	7287429600
SSP3 - 4.5	2100	4.6153E+10	51128708300	484256100	9519297300	7575811500
SSP3 - 6.0	2005	2274624100	0	246084000	0	3254988500
SSP3 - 6.0	2010	2638405600	207424500	270010500	0	3546514000
SSP3 - 6.0	2020	3346379800	563275100	317845300	23807300	4124060500
SSP3 - 6.0	2030	4322101800	1292808800	356208900	77975800	4694950500
SSP3 - 6.0	2040	6725491200	3885274800	383866700	495259600	5191114100
SSP3 - 6.0	2050	1.2536E+10	10763098200	406531800	1756074100	5676127200
SSP3 - 6.0	2060	1.884E+10	18285814500	426101500	3148049600	6131327800
SSP3 - 6.0	2070	2.5992E+10	26873695300	444496000	4760068500	6571400300
SSP3 - 6.0	2080	3.0861E+10	32607824600	462349700	5824427100	6985566500
SSP3 - 6.0	2090	3.4918E+10	37324825400	479432700	6713919300	7378238300
SSP3 - 6.0	2100	4.0564E+10	44021687900	495667000	8013229100	7769912000
SSP3 - Bas	2005	2274624100	0	246084000	0	3254988500
SSP3 - Bas	2010	2639070000	208276400	270004500	0	3546642500
SSP3 - Bas	2020	3331128200	543713500	317867200	22811500	4121289300
SSP3 - Bas	2030	4221368300	1165691900	356336400	59736300	4688856900
SSP3 - Bas	2040	5306526100	2108307500	384612200	147776500	5187355300
SSP3 - Bas	2050	6859370600	3665047700	408098000	346547600	5663504100
SSP3 - Bas	2060	8613413500	5505120900	428164000	610618400	6099001000
SSP3 - Bas	2070	1.057E+10	7601542900	447496900	950184300	6502512900
SSP3 - Bas	2080	1.2466E+10	9614233500	466442000	1299555400	6887710300
SSP3 - Bas	2090	1.3999E+10	11167458400	484770400	1579741300	7260640500
SSP3 - Bas	2100	1.581E+10	13059988700	502721500	1932907900	7639074400
SSP4 - 2.6	2005					
SSP4 - 2.6	2010	3256111096	1395044483	193120081.3	0	3480772607
SSP4 - 2.6	2020	3688065943	2055162772	226782507.4	416119337.7	3733450529
SSP4 - 2.6	2030	4056775148	4258197145	249934204.3	1415325744	4106028838
SSP4 - 2.6	2040	4337267449	5901712417	268136529.4	2632015002	4390872346
SSP4 - 2.6	2050	4536958025	7638197466	282536393.6	3811926627	4618779235
SSP4 - 2.6	2060	4621558929	10530066280	287200487.6	5839342348	4791391396
SSP4 - 2.6	2070	4631168732	13720115300	286203612.4	7744104124	4919074582
SSP4 - 2.6	2080	4574436826	16720568310	280748814.5	9427417241	4823136164
SSP4 - 2.6	2090	4460587084	19412784120	270089955.8	10794232500	4507491963
SSP4 - 2.6	2100	4320295803	23382926660	257851582.8	11875246740	4339484585
SSP4 - 3.4	2005					
SSP4 - 3.4	2010	3256111096	1395044483	193120081.3	0	3480772608

SSP4 - 3.4	2020	3688065943	2055162772	226782507.4	416119349.5	3733450818
SSP4 - 3.4	2030	4065408416	3463103048	251364275.2	809967869.6	4111201746
SSP4 - 3.4	2040	4366079065	4499070945	271523728.1	1401410885	4411540553
SSP4 - 3.4	2050	4599917934	5460304167	288599036.2	2030468052	4649384202
SSP4 - 3.4	2060	4717078697	7157216458	295632702.3	3319492453	4790891641
SSP4 - 3.4	2070	4764389428	9439653165	297221030.5	4981006890	4901687526
SSP4 - 3.4	2080	4743325249	12504323010	293813742.2	7006761445	4998394008
SSP4 - 3.4	2090	4640694514	15652634050	284739256.4	8872495698	4950759336
SSP4 - 3.4	2100	4520489840	18310555540	273574855.9	10415977160	4656175021
SSP4 - 4.5	2005					
SSP4 - 4.5	2010	3256111096	1395044483	193120081.3	0	3480772608
SSP4 - 4.5	2020	3688065943	2055162772	226782507.4	416119349.5	3733450818
SSP4 - 4.5	2030	4069388299	3134398163	252019096.3	694478796.2	4114065334
SSP4 - 4.5	2040	4379321638	4069379209	273209268.5	1026342599	4423510300
SSP4 - 4.5	2050	4631730624	4764042079	291829345.3	1439663950	4676678990
SSP4 - 4.5	2060	4768264870	5779588519	300213929.5	2191441997	4821543573
SSP4 - 4.5	2070	4840582218	7101882306	303464075.8	3189633018	4917135902
SSP4 - 4.5	2080	4919420978	7667474162	307518762.8	3603229438	5022206403
SSP4 - 4.5	2090	4940141114	8004922179	306890861.3	3861042914	5063430600
SSP4 - 4.5	2100	4921290329	8938689741	303336930	4582757083	5083913288
SSP4 - 6.0	2005					
SSP4 - 6.0	2010	3256111096	1395044483	193120081.3	0	3480772608
SSP4 - 6.0	2020	3688065943	2055162772	226782507.4	416119349.5	3733450818
SSP4 - 6.0	2030	4075308094	2719598698	252973984.1	575134101.5	4118197255
SSP4 - 6.0	2040	4400629550	3350646210	275974186.1	747468307.6	4444520472
SSP4 - 6.0	2050	4681811061	3871040683	297647864.3	894189174.5	4726210114
SSP4 - 6.0	2060	4861749764	4462581725	309141212.1	1101942473	4908311613
SSP4 - 6.0	2070	4990659644	4722943634	316251769.1	1228501030	5039111504
SSP4 - 6.0	2080	5075092902	4938958937	319763915.7	1373609897	5126279379
SSP4 - 6.0	2090	5091903767	5132000307	318052955.6	1530004098	5147582389
SSP4 - 6.0	2100	5086261651	5471607722	314753919.2	1819424521	5152509904
SSP4 - Bas	2005				0	3097622458
SSP4 - Bas	2010				0	3480772608
SSP4 - Bas	2020				377877064.1	3731899247
SSP4 - Bas	2030				590799514.6	4122075488
SSP4 - Bas	2040				794897032.3	4453221493
SSP4 - Bas	2050				955881565.5	4749315991
SSP4 - Bas	2060				1169169265	4940717374
SSP4 - Bas	2070				1246357131	5090665457
SSP4 - Bas	2080				1297554051	5205640017
SSP4 - Bas	2090				1310590368	5263731014
SSP4 - Bas	2100				1310732448	5314130224
SSP5 - 1.9	2005		25325500	205757600	25325500	3327675000
SSP5 - 1.9	2010		11213800	235413800	11213800	3758394200
SSP5 - 1.9	2020		83659900	303699700	83659900	4525046700
SSP5 - 1.9	2030		394567300	382277900	394567300	4953645200
SSP5 - 1.9	2040		5939708200	463265700	5939708200	5364107000

SSP5 - 1.9	2050	15281369200	520819300	15281369200	5828327900
SSP5 - 1.9	2060	17786588100	555408400	17786588100	6174538200
SSP5 - 1.9	2070	19348541000	572768000	19348541000	6417277200
SSP5 - 1.9	2080	20623793500	573378800	20623793500	6451233300
SSP5 - 1.9	2090	20715263700	558313300	20715263700	6365479100
SSP5 - 1.9	2100	20914702600	526916100	20914702600	6159845700
SSP5 - 2.6	2005	25325500	205757500	25325500	3327677400
SSP5 - 2.6	2010	11213800	235444900	11213800	3758809400
SSP5 - 2.6	2020	83659900	304184700	83659900	4527751900
SSP5 - 2.6	2030	129415800	382473000	129415800	4946967800
SSP5 - 2.6	2040	1316341200	460410300	1316341200	5317633100
SSP5 - 2.6	2050	7409837300	515365200	7409837300	5753868500
SSP5 - 2.6	2060	14742592600	548486200	14742592600	6052379200
SSP5 - 2.6	2070	17720538700	566200900	17720538700	6333484500
SSP5 - 2.6	2080	19564870900	569582500	19564870900	6361395800
SSP5 - 2.6	2090	21543209900	557599900	21543209900	6314436100
SSP5 - 2.6	2100	23142312000	530170700	23142312000	6170332500
SSP5 - 3.4	2005	25325500	205757500	25325500	3327677400
SSP5 - 3.4	2010	11213800	235444900	11213800	3758809400
SSP5 - 3.4	2020	83659900	304184700	83659900	4527751900
SSP5 - 3.4	2030	74239100	386507800	74239100	4950724100
SSP5 - 3.4	2040	109734000	460248100	109734000	5335194400
SSP5 - 3.4	2050	1157429900	514826600	1157429900	5716099500
SSP5 - 3.4	2060	5030808100	546835200	5030808100	6003412000
SSP5 - 3.4	2070	9704882200	562247800	9704882200	6179976400
SSP5 - 3.4	2080	14470651000	563882300	14470651000	6239495900
SSP5 - 3.4	2090	18761840600	551415000	18761840600	6211186900
SSP5 - 3.4	2100	19915488200	526742700	19915488200	6163501900
SSP5 - 4.5	2005	25325500	205757500	25325500	3327677400
SSP5 - 4.5	2010	11213800	235444900	11213800	3758809400
SSP5 - 4.5	2020	83659900	304184700	83659900	4527751900
SSP5 - 4.5	2030	150668900	386503200	150668900	4950044500
SSP5 - 4.5	2040	290556700	466501500	290556700	5329383300
SSP5 - 4.5	2050	1161593700	514563500	1161593700	5713119500
SSP5 - 4.5	2060	3640707100	546391600	3640707100	5987242400
SSP5 - 4.5	2070	6093771000	561872000	6093771000	6141264400
SSP5 - 4.5	2080	7813299700	561299700	7813299700	6245597000
SSP5 - 4.5	2090	9197138000	546428900	9197138000	6180184300
SSP5 - 4.5	2100	9364927000	519190000	9364927000	6053412500
SSP5 - 6.0	2005	25325500	205757500	25325500	3327677400
SSP5 - 6.0	2010	11213800	235444900	11213800	3758809400
SSP5 - 6.0	2020	83659900	304184700	83659900	4527751900
SSP5 - 6.0	2030	74863100	386616700	74863100	4949998700
SSP5 - 6.0	2040	68809800	467425800	68809800	5333209800
SSP5 - 6.0	2050	58666700	521808800	58666700	5766910000
SSP5 - 6.0	2060	136672100	556845100	136672100	6059344900
SSP5 - 6.0	2070	240499400	570324700	240499400	6211292400

SSP5 - 6.0	2080	325319900	560996900	325319900	6313681400
SSP5 - 6.0	2090	603295700	545549300	603295700	6299093700
SSP5 - 6.0	2100	1246222200	517856900	1246222200	6174619000
SSP5 - Bas	2005	25325500	205757600	25325500	3327675000
SSP5 - Bas	2010	11213800	235413800	11213800	3758394200
SSP5 - Bas	2020	84564500	304241300	84564500	4523136000
SSP5 - Bas	2030	87532000	385223300	87532000	4942283400
SSP5 - Bas	2040	66829400	465109600	66829400	5320627700
SSP5 - Bas	2050	31205900	517348100	31205900	5759041800
SSP5 - Bas	2060	34324900	545685900	34324900	6029989800
SSP5 - Bas	2070	23590300	559745300	23590300	6208571100
SSP5 - Bas	2080	17276100	558366700	17276100	6308108600
SSP5 - Bas	2090	58895100	543481600	58895100	6297922900
SSP5 - Bas	2100	189018000	516273100	189018000	6197840500

Livestock production	Carbon price	Methane concentra tion	CO2 concentrat ion	Nitrous oxide concentration	Economic consumpti on	Economic consumption (\$)	Electricity capacity	Biomass capacity
238986500	0	1753.16	379.85	319.855	34531.7	3.4532E+13	3797.849	66.79926
262440781	0	1812.864	390.5053	323.68957	40443	4.0443E+13	4523.66	80.58772
289096875	0	1812.021	412.142	330.4511	60738.12	6.0738E+13	5775.863	185.2419
309853906	303.6736	1631.172	424.6815	335.06455	94211.73	9.4212E+13	5656.165	223.6486
324523656	546.2075	1449.081	425.5272	337.95418	136888.2	1.3689E+14	8287.41	315.4962
339193531	651.0314	1325.072	420.4756	340.41814	181033.2	1.8103E+14	12255.13	429.8082
332888750	707.6402	1250.522	413.8763	342.5171	220858.8	2.2086E+14	14395.68	577.2766
326584125	652.1972	1212.159	406.7838	344.55001	259777.6	2.5978E+14	14604.41	665.2974
320279438	519.7958	1180.458	398.6285	346.6581	294820.9	2.9482E+14	15802.23	711.3799
313974688	335.337	1149.776	389.0571	348.81946	326094.8	3.2609E+14	16652.92	742.3571
307670063	238.8175	1122.537	377.8966	350.98969	352095.3	3.521E+14	16096.66	823.8782
238986500	0	1753.16	379.85	319.855	34531.7	3.4532E+13	3797.849	66.79926
262440781	0	1812.864	390.5053	323.68957	40443	4.0443E+13	4523.677	77.9239
289096875	8.815058	1825.457	414.5497	330.53829	60738.12	6.0738E+13	5988.858	98.95163
309853906	32.72195	1682.249	436.5426	335.65605	94211.73	9.4212E+13	7658.348	97.17514
324523656	71.76319	1519.876	452.2906	339.02523	136888.2	1.3689E+14	9966.742	119.6849
339193531	99.9675	1399.942	460.6929	341.45747	181033.2	1.8103E+14	13132.94	239.4739
332888750	109.9755	1323.012	462.9022	343.47673	220858.8	2.2086E+14	15596.44	453.1193
326584125	148.1949	1271.819	460.6425	345.3853	259777.6	2.5978E+14	17002.01	552.336
320279438	242.5839	1218.766	453.8621	347.39661	294820.9	2.9482E+14	17462.69	671.9833
313974688	185.9612	1176.121	443.0907	349.76675	326094.8	3.2609E+14	16869.16	726.1218
307670063	139.7415	1147.289	432.1714	352.18893	352095.3	3.521E+14	18843.58	549.8993
238986500	0	1753.16	379.85	319.855	34531.7	3.4532E+13	3797.849	66.79926
262440781	0	1812.864	390.5053	323.68957	40443	4.0443E+13	4523.683	77.45602
289174781	0.581091	1873.121	415.1411	330.89811	60738.12	6.0738E+13	6059.375	92.20828
310123281	5.429163	1805.508	440.2962	337.18927	94211.73	9.4212E+13	7996.874	83.13839
324986813	16.70841	1655.813	463.8594	341.99197	136888.2	1.3689E+14	10562.71	57.22467
339850250	22.9549	1528.223	484.0237	345.35377	181033.2	1.8103E+14	14482.27	33.87289
333571594	32.80486	1439.063	499.883	347.75557	220858.8	2.2086E+14	17447.77	22.50634
327292813	61.89357	1357.795	510.1736	349.53688	259777.6	2.5978E+14	19605.84	24.61589
321014156	117.0125	1279.19	512.5219	350.96796	294820.9	2.9482E+14	20277.72	128.4759
314735500	137.5331	1213.912	505.941	352.59674	326094.8	3.2609E+14	19201.58	466.705
308456750	109.8531	1173.123	494.1748	354.75319	352095.3	3.521E+14	19081.28	563.5472
238986500	0	1753.16	379.85	319.855	34531.7	3.4532E+13	3797.849	66.79926
262440781	0	1812.864	390.5053	323.68957	40443	4.0443E+13	4523.684	77.38485
289206813	0.555831	1877.987	415.2466	330.92228	60738.12	6.0738E+13	6068.441	91.82623
310242688	0.81623	1840.18	441.2687	337.48254	94211.73	9.4212E+13	8032.07	77.22823

325304500	3.516333	1744.674	467.459	343.16175	136888.2	1.3689E+14	10718.09	42.19052
340366281	3.035026	1653.497	492.6737	348.03006	181033.2	1.8103E+14	14647.24	19.05672
334133469	7.290082	1575.082	516.0629	351.9978	220858.8	2.2086E+14	18031.06	8.565082
327900656	15.59974	1488.02	536.3393	354.80745	259777.6	2.5978E+14	21018.01	9.012983
321667844	29.58919	1394.327	551.1038	356.54991	294820.9	2.9482E+14	22692.61	7.202462
315435063	45.20924	1305.92	559.8281	357.64416	326094.8	3.2609E+14	22780.28	8.170709
309202250	46.74554	1231.064	563.6224	358.4312	352095.3	3.521E+14	21798.34	10.44637
238986500	0	1753.16	379.85	319.855	34531.7	3.4532E+13	3797.849	66.79926
262440781	0	1812.864	390.5053	323.68957	40443	4.0443E+13	4523.684	77.37998
289282281	0	1888.198	415.3473	330.99404	60738.12	6.0738E+13	6069.227	91.68074
310456313	0	1919.771	442.3016	337.94414	94211.73	9.4212E+13	8037.996	78.89134
325796219	0	1935.294	470.4785	344.412	136888.2	1.3689E+14	10769.04	45.04761
341136156	0	1915.28	498.1738	350.15178	181033.2	1.8103E+14	14619.31	20.84762
334972156	0	1864.652	524.9761	355.07787	220858.8	2.2086E+14	18047.77	9.974223
328808188	0	1797.688	550.8283	359.34345	259777.6	2.5978E+14	21290.03	6.351494
322644125	0	1708.398	573.5107	363.0708	294820.9	2.9482E+14	24044.46	2.116298
316480156	0	1610.532	592.2589	366.25585	326094.8	3.2609E+14	24659.91	1.360061
310316094	0	1526.825	608.3543	368.78591	352095.3	3.521E+14	23770.85	1.166945
216129997	0	1753.16	379.85	319.855	29260.07	2.926E+13	3866.032	28.054
233117496	0	1812.864	390.5053	323.68957	35984.91	3.5985E+13	4745.827	39.998
274615832	31.71469	1880.258	414.0699	331.1026	51240.54	5.1241E+13	6202.269	63.524
312901169	95.13056	1810.255	429.8439	338.05493	82756.7	8.2757E+13	9607.534	56.988
320698974	267.5762	1635.095	433.5009	343.70178	114534.2	1.1453E+14	15405.07	33.778
310942612	435.8535	1476.623	430.8554	347.33493	149628.8	1.4963E+14	21595.19	28.509
291049273	709.9594	1363.518	424.585	349.17142	190133.9	1.9013E+14	28366.23	60.037
276707794	1156.449	1280.619	415.4299	349.77779	239875.4	2.3988E+14	36296.04	136.112
261323787	1883.734	1211.112	404.045	349.45018	297032.5	2.9703E+14	43553.5	207.955
244389578	3068.404	1155.015	391.9963	348.55001	366052.7	3.6605E+14	51066.47	209.617
226570798	4998.106	1114.438	380.6867	347.15951	431221.9	4.3122E+14	61611.73	176.198
216129997	0	1753.16	379.85	319.855	29260.07	2.926E+13	3861.915	28.054
233117496	0	1812.864	390.5053	323.68957	35968.52	3.5969E+13	4743.791	41.329
274382410	31.68069	1881.124	413.9484	331.10772	51126.21	5.1126E+13	6211.32	64.994
315811043	41.84239	1855.488	434.8058	338.36295	82718	8.2718E+13	8218.418	53.36
345656412	52.00433	1746.234	449.9244	345.01008	115650.1	1.1565E+14	10848.66	27.736
360684725	84.70958	1606.051	458.165	350.35926	152349.2	1.5235E+14	15167.44	21.779
360853169	137.983	1505.438	459.9349	354.36652	194035.5	1.9404E+14	20526.9	47.155
357231064	224.7597	1444.547	456.4663	357.27174	244657.6	2.4466E+14	27822.45	103.425
346840839	366.1099	1394.917	448.5629	358.88701	302949.5	3.0295E+14	36541.3	151.521
331033308	596.3545	1335.874	438.7988	359.36443	373619.8	3.7362E+14	48156.67	160.496
314039960	971.3986	1275.33	429.0485	359.03906	442937.8	4.4294E+14	62843.83	148.622
216129997	0	1753.16	379.85	319.855	29260.07	2.926E+13	3861.915	28.054
233117496	0	1812.864	390.5053	323.68957	35960.02	3.596E+13	4743.789	41.329
275496712	21.63314	1884.083	414.4386	331.13802	51114.38	5.1114E+13	6192.776	64.964
317292079	20.10046	1890.372	439.2827	338.57833	82767.6	8.2768E+13	7511.445	51.62
350854242	18.56781	1823.353	463.0454	345.72261	115945.3	1.1595E+14	10112.83	26.643
374643895	30.24501	1697.128	483.2405	351.98161	153094.2	1.5309E+14	13602.65	34.703
386990181	49.26593	1589.186	497.4908	357.16312	195123.4	1.9512E+14	18455.56	54.162

392618685	80.249	1526.255	504.2789	361.32583	246434.5	2.4643E+14	23212.07	90.37
392091973	130.7172	1489.05	504.7783	364.17981	305485.3	3.0549E+14	28911.27	116.217
381399373	212.9245	1455.54	500.7113	365.74437	376695.2	3.767E+14	38544.97	134.479
365387690	346.8316	1414.785	494.1501	366.467	447772.1	4.4777E+14	49805.42	153.465
216129997	0	1753.16	379.85	319.855	29260.07	2.926E+13	3861.915	28.054
233117496	0	1812.864	390.5053	323.68957	35957.38	3.5957E+13	4743.784	41.329
275839085	17.74189	1886.886	414.723	331.15308	51111.88	5.1112E+13	6135.799	64.906
317729577	12.65402	1904.956	440.9205	338.65501	82756.4	8.2756E+13	7514.178	51.225
352634669	7.56615	1874.503	468.5304	346.00617	116027.2	1.1603E+14	9811.851	18.232
380686753	12.32447	1789.139	496.0661	352.7215	153329.3	1.5333E+14	12781.51	10.977
399023954	20.07526	1685.763	521.3235	358.63911	195635.7	1.9564E+14	17148.89	17.589
409914104	32.70048	1612.579	542.5851	363.72682	247252.8	2.4725E+14	21999.79	29.181
414819298	53.26563	1564.646	558.1323	367.55064	306723.9	3.0672E+14	26179.14	57.197
411139333	86.7641	1529.2	565.6875	370.03535	378385.4	3.7839E+14	31982.53	89.57
401639483	141.3296	1506.556	566.8592	371.52198	450110.5	4.5011E+14	39926.63	117.91
216129997	0	1753.16	379.85	319.855	29260.07	2.926E+13	3861.915	28.054
233117496	0	1812.864	390.5053	323.68957	35955.99	3.5956E+13	4743.775	41.329
276120344	15.47938	1890.3	414.7737	331.17027	51108.16	5.1108E+13	6130.903	64.921
318008551	8.46162	1927.638	441.8382	338.7274	82723.1	8.2723E+13	7448.995	51.194
354213554	1.44383	1948.519	472.5694	346.23655	116038.7	1.1604E+14	9540.811	27.501
383735171	2.35185	1928.786	506.9615	353.30509	153422.4	1.5342E+14	12205.32	51.415
406764622	3.83092	1874.066	544.0904	359.82147	195810.1	1.9581E+14	16207.55	55.807
422765346	6.24016	1817.103	582.678	365.81451	247571.6	2.4757E+14	21073.49	65.489
432640242	10.16456	1755.77	622.368	370.9661	307438.4	3.0744E+14	25593.41	124.397
437128597	16.557	1692.872	663.0393	375.34096	379774	3.7977E+14	30169.65	162.429
435639161	26.9696	1631.38	704.272	379.21409	452128.5	4.5213E+14	34356.03	224.521
216129997	0	1753.16	379.85	319.855	29260.07	2.926E+13	3861.914	28.054
233117496	0	1812.864	390.5053	323.68957	35949.84	3.595E+13	4744.362	41.329
276592208	0	1898.442	414.7085	331.20346	51099.36	5.1099E+13	6107.277	64.807
318148911	0	1951.761	442.0015	338.96954	82715.8	8.2716E+13	7369.049	51.158
354609433	0	1995.014	474.0147	346.98686	116057.1	1.1606E+14	9344.282	31.535
384838091	0	2022.441	511.3055	354.93155	153434.1	1.5343E+14	11723.14	61.244
409034748	0	2046.626	553.6277	362.71977	195843.8	1.9584E+14	15379.52	58.658
426433917	0	2070.316	600.7577	370.34052	247576.3	2.4758E+14	19987.46	69.37
439297009	0	2081.128	655.1408	377.75383	307536.2	3.0754E+14	23372.61	123.832
447270075	0	2076.744	718.6013	385.17079	379937.4	3.7994E+14	27358.87	167.982
451089114	0	2053.971	789.8492	392.735	452564.8	4.5256E+14	32712.35	220.338
246084000	0	1753.16	379.85	319.855	33809.15	3.3809E+13	3509.874	61.511
270010500	2.4627	1812.864	390.5053	323.68957	37621.01	3.7621E+13	3963.362	61.4859
317845300	15.5657	1947.572	417.0736	331.54097	51123.02	5.1123E+13	4959.581	68.6987
355994500	87.4244	2091.554	447.3265	340.01592	63536.22	6.3536E+13	6067.887	87.2065
381268700	128.3259	2065.384	470.7605	346.96881	70945.76	7.0946E+13	7374.341	380.5091
401796500	184.2533	1884.667	483.42	351.88448	76480	7.648E+13	9163.966	1006.095
419259500	248.1855	1767.598	490.4725	356.89933	80945.33	8.0945E+13	11114.65	1488.789
434614600	409.54	1722.833	492.7602	361.86602	85128.07	8.5128E+13	13831.87	2247.692
449019900	626.8813	1697.964	490.7222	366.56202	88788.92	8.8789E+13	16853.51	2742.318
461911900	883.3675	1686.443	485.8113	371.04304	92315.26	9.2315E+13	20267.65	3162.051

473973200	1167.677	1683.682	479.1328	375.35505	96607.06	9.6607E+13	23927.29	3477.71
246084000	0	1753.16	379.85	319.855	33809.15	3.3809E+13	3509.874	61.511
270010500	2.4627	1812.864	390.5053	323.68957	37621.01	3.7621E+13	3963.362	61.4859
317845300	15.5724	1947.549	417.0741	331.54097	51123.02	5.1123E+13	4959.581	68.6987
356197800	23.4267	2101.869	448.4431	340.19197	63700.27	6.37E+13	6129.82	79.9146
383253300	40.6628	2104.731	477.9609	347.92203	72119.12	7.2119E+13	6937.65	223.0096
405031800	64.5764	1978.413	501.4905	354.08111	78110.31	7.811E+13	8018.881	721.3256
422248000	120.9541	1891.902	517.6443	360.10596	82321.25	8.2321E+13	9859.132	1487.574
439808400	160.1478	1858.469	527.0577	365.97883	87159.24	8.7159E+13	11174.05	1733.021
456706400	212.896	1861.385	533.9179	371.89534	91768.47	9.1768E+13	12916.25	2087.833
471661200	297.6163	1871.741	538.5743	377.71958	96084.15	9.6084E+13	15252.8	2475.149
484256100	446.9148	1872.287	540.1797	383.24781	100482	1.0048E+14	18324.63	2945.424
246084000	0	1753.16	379.85	319.855	33809.15	3.3809E+13	3509.874	61.511
270010500	2.4627	1812.864	390.5053	323.68957	37621.01	3.7621E+13	3963.362	61.4859
317845300	15.5806	1947.541	417.0743	331.54097	51123.02	5.1123E+13	4959.581	68.6987
356208900	19.8577	2103.183	448.5531	340.21418	63709.74	6.371E+13	6144.141	79.1864
383866700	19.9509	2143.032	480.627	348.42214	72494.86	7.2495E+13	7012.652	200.8666
406531800	28.588	2074.852	511.4254	355.60202	78984.87	7.8985E+13	7947.629	596.0419
426101500	28.588	2060.36	542.9487	363.05868	84404.11	8.4404E+13	8835.031	1036.437
444496000	41.052	2087.458	573.5018	370.72911	89674.62	8.9675E+13	9718.766	1546.525
462349700	57.4871	2110.954	599.9446	378.28435	94527.96	9.4528E+13	10912.8	1872.692
479432700	68.734	2143.896	623.1286	385.83276	99638.89	9.9639E+13	12354.12	2141.931
495667000	82.7129	2185.218	645.0564	393.44522	105504	1.055E+14	14109.11	2547.411
246084000		1753.16	379.85	319.855	33809.15	3.3809E+13	3509.874	61.511
270004500		1812.864	390.5053	323.68957	37619.94	3.762E+13	3958.756	61.4885
317867200		1958.352	417.8888	331.73189	51141.04	5.1141E+13	4997.764	68.3768
356336400		2136.883	451.9973	340.94348	63820.12	6.382E+13	6151.372	77.3847
384612200		2314.385	491.2553	350.99258	73023.94	7.3024E+13	7270.561	96.2335
408098000		2478.77	535.2207	361.56127	79955.97	7.9956E+13	8559.191	142.8895
428164000		2634.316	583.6923	372.57319	85600.53	8.5601E+13	9573.995	206.1249
447496900		2785.519	636.942	384.04251	91401.29	9.1401E+13	10537.99	292.5306
466442000		2936.525	695.6742	395.9181	96993.27	9.6993E+13	11555.6	378.8032
484770400		3087.259	760.9923	408.1424	102821	1.0282E+14	12614.94	441.1172
502721500		3238.033	834.3412	420.66149	109425	1.0943E+14	13777.87	524.289
177627720								
193120126	0	1812.864	390.5053	323.68957			4144.848	30.33453
226782499	0	1921.036	415.2453	331.16247			4956.901	54.48332
249935026	69.90315	1940.883	433.1226	338.29319			7028.708	199.7464
268141071	113.8651	1926.957	440.3508	345.23687			9166.479	351.7711
282535985	185.4743	1947.835	444.1231	352.66659			11391.09	542.4349
287181247	302.118	1963.588	445.2066	360.51557			13354.96	728.6418
286189684	492.118	1964.091	442.356	368.70911			15198.07	893.285
280744657	801.6094	1937.045	433.2123	376.95326			16549.98	1062.837
270100951	1305.737	1889.896	417.6145	384.75886			17760.8	1324.284
257931574	2126.906	1841.637	397.1594	391.96667			18831.28	2204.843
177627720								
193120126	0	1812.864	390.5053	323.68957			4144.848	30.33455

226782499	0	1921.036	415.2453	331.16247			4956.901	54.4833
251364608	34.6142	1959.573	438.4117	338.47259			6518.121	110.0375
271523958	56.38304	1970.224	455.5431	345.72203			8319.422	187.9401
288599695	91.84176	1997.525	466.391	353.27912			10221.17	302.1048
295633934	149.6004	2016.221	472.5781	361.08338			12091.92	439.8529
297222474	243.6834	2027.33	476.0988	369.12603			13951.78	615.4754
293815594	396.9357	2017.851	475.603	377.4044			15396.86	777.819
284751538	646.5664	1984.089	468.5495	385.73505			16603.51	925.6869
273645188	1053.186	1935.698	454.8193	393.68536			17731.03	1152.563
177627720								
193120126	0	1812.864	390.5053	323.68957			4144.848	30.33455
226782499	0	1921.036	415.2453	331.16247			4956.901	54.4833
252019242	20.34388	1974.549	440.5192	338.64818			6370.159	95.63851
273209686	33.13803	2005.847	463.4998	346.25932			7935.955	145.885
291830163	53.97845	2043.44	481.6414	354.10516			9569.76	208.0479
300215009	87.92494	2063.284	493.5641	362.05714			11272.62	288.2907
303465522	143.2207	2071.441	500.919	370.07464			13020.66	415.6971
307520497	147.267	2073.759	505.1717	378.27386			13587.94	451.2379
306897898	157.5793	2080.462	508.5128	386.62144			14078.32	489.8371
303384299	201.0655	2089.317	511.8824	394.97277			14880.55	560.0934
177627720								
193120126	0	1812.864	390.5053	323.68957			4144.848	30.33455
226782499	0	1921.036	415.2453	331.16247			4956.901	54.4833
252974249	2.114418	2038.132	443.7189	339.5447			6335.965	84.77068
275974756	3.444164	2159.899	475.6372	349.23327			7604.555	117.7359
297648599	5.610189	2245.016	508.4056	359.19614			8721.818	146.8847
309142476	9.138373	2293.199	540.5294	369.02267			9808.207	170.6041
316252984	14.88548	2314.926	571.1252	378.45966			10828.11	188.9121
319765569	24.24685	2307.729	597.5109	387.34773			11729.7	195.8065
318058340	39.4956	2280.985	617.5458	395.72455			12594.73	193.9123
314795554	64.33409	2249.813	631.4741	403.76233			13500.73	190.5601
177627720	0	1753.16	379.85	319.855			3733.243	20.20767
193120126	0	1812.864	390.5053	323.68957			4144.848	30.33455
226806023	0	1945.321	415.996	331.53214			5044.324	51.8459
253093463	0	2117.301	446.6259	340.42382			6396.628	82.34672
276367922	0	2304.988	482.375	350.4322			7647.878	112.0634
298845781	0	2451.961	520.9601	361.25518			8731.882	137.1466
310854798	0	2554.269	561.3776	372.62274			9722.47	157.7131
319025194	0	2632.626	602.9313	384.30634			10591.25	176.4068
324128626	0	2671.109	643.1318	396.20072			11257.65	184.6751
324630715	0	2675.739	681.1994	408.17059			11766.1	182.7066
324481161	0	2668.365	718.3727	420.18297			12184.82	169.1904
205757600	0	1753.16	379.85	319.855	29680	2.968E+13	3557	23.92
235413800	0	1812.864	390.5053	323.68957	32950	3.295E+13	4176	34.61
303699700	7.333	1904.271	414.9077	331.13662	47109.47	4.7109E+13	5795	45.62
382277900	96.32	1822.309	439.2346	337.69586	69285.84	6.9286E+13	7042	78.22
463265700	348.8	1617.625	454.8986	343.5938	100751.7	1.0075E+14	11450	310.1

520819300	628.6	1475.146	453.7367	350.82057	138836.7	1.3884E+14	21640	457.8
555408400	1204	1386.759	438.6597	358.63934	184923.2	1.8492E+14	34490	535.8
572768000	1724	1335.886	419.4862	365.31553	223917.6	2.2392E+14	47900	626.4
573378800	2904	1300.28	401.9195	371.12852	285116.2	2.8512E+14	62360	721.3
558313300	4681	1264.49	385.7025	376.29198	342716.6	3.4272E+14	76770	759.8
526916100	7464	1222.31	370.1514	380.3818	402916.9	4.0292E+14	87410	755.9
205757500	0	1753.16	379.85	319.855	29680	2.968E+13	3557	23.92
235444900	0	1812.864	390.5053	323.68957	32950	3.295E+13	4176	34.61
304184700	7.333	1904.687	414.8545	331.11989	47109.47	4.7109E+13	5795	45.62
382473000	41.95	1881.677	441.7258	338.0393	70400.51	7.0401E+13	7603	68.05
460410300	143.3	1741.925	467.4384	343.84257	105659.5	1.0566E+14	10100	118.1
515365200	258.4	1601.803	484.0805	349.08025	147340.1	1.4734E+14	15600	110.9
548486200	493.1	1507.179	486.7812	355.04402	194126.2	1.9413E+14	25070	101.9
566200900	704.8	1434.51	477.7632	361.60235	234018	2.3402E+14	37390	114.4
569582500	1193	1365.116	463.0492	367.55417	296318.5	2.9632E+14	52730	184.2
557599900	1938	1295.545	445.6751	372.73883	353321	3.5332E+14	70400	416.5
530170700	3106	1237.088	427.6169	377.31904	413219.6	4.1322E+14	83230	604.6
205757500	0	1753.16	379.85	319.855	29680	2.968E+13	3557	23.92
235444900	0	1812.864	390.5053	323.68957	32950	3.295E+13	4176	34.61
304184700	7.333	1904.7	414.8492	331.11989	47109.47	4.7109E+13	5795	45.62
386507800	23.59	1930.817	442.3492	338.19333	70515.71	7.0516E+13	7844	61.1
460248100	72.53	1857.46	471.4091	344.43327	106576	1.0658E+14	10060	94.89
514826600	131.4	1730.107	496.6991	349.22238	149949.3	1.4995E+14	13840	108.7
546835200	251.7	1615.035	514.7885	352.94863	198225.1	1.9823E+14	20640	93.46
562247800	359.5	1525.964	522.9733	357.10367	238718.4	2.3872E+14	30450	76.8
563882300	607.1	1443.366	520.2652	361.80904	301715.2	3.0172E+14	44230	83.6
551415000	980.8	1358.624	508.3498	366.72618	360220.3	3.6022E+14	61050	208.5
526742700	1570	1278.011	491.476	371.19061	420621.6	4.2062E+14	74990	370.2
205757500	0	1753.16	379.85	319.855	29680	2.968E+13	3557	23.92
235444900	0	1812.864	390.5053	323.68957	32950	3.295E+13	4176	34.61
304184700	7.333	1904.698	414.8458	331.11989	47109.47	4.7109E+13	5795	45.62
386503200	22.29	1933.404	442.5619	338.2332	70566.16	7.0566E+13	7879	69.29
466501500	56.71	1891.892	473.0421	344.67055	106879.8	1.0688E+14	10100	151.1
514563500	92.38	1792.092	502.3879	349.95626	150964.1	1.5096E+14	13380	244.1
546391600	150.5	1673.229	527.4181	353.98335	200536.6	2.0054E+14	18220	252.5
561872000	215.6	1586.78	546.0745	357.56503	242421.1	2.4242E+14	25580	223
561299700	280.8	1518.442	559.1474	360.97849	307817.1	3.0782E+14	35910	153.3
546428900	345.9	1444.797	567.6406	363.92471	369218.9	3.6922E+14	47540	72.64
519190000	411.1	1361.71	573.7102	366.05058	432820.7	4.3282E+14	55870	38.1
205757500	0	1753.16	379.85	319.855	29680	2.968E+13	3557	23.92
235444900	0	1812.864	390.5053	323.68957	32950	3.295E+13	4176	34.61
304184700	7.333	1904.691	414.8542	331.11989	47109.47	4.7109E+13	5795	45.62
386616700	11.72	1970.243	443.9563	338.41985	70638.24	7.0638E+13	7982	60.64
467425800	22.27	2017.185	479.7991	345.45721	107493.4	1.0749E+14	10330	106.7
521808800	36.28	2017.896	520.1116	351.56325	152483.9	1.5248E+14	13130	221.3
556845100	59.1	1950.076	562.3711	356.30627	203070.1	2.0307E+14	16350	387.1
570324700	84.68	1829.418	603.3297	360.09284	245660.7	2.4566E+14	21310	519.2

560996900	110.3	1679.353	640.6846	363.03054	311550.5	3.1155E+14	29390	569.5
545549300	135.9	1541.429	673.4373	365.0222	372638.7	3.7264E+14	39870	553.4
517856900	161.4	1432.861	702.3926	365.88887	436331.5	4.3633E+14	48250	558.4
205757600	0	1753.16	379.85	319.855	29680	2.968E+13	3557	23.92
235413800	0	1812.864	390.5053	323.68957	32950	3.295E+13	4176	34.61
304241300	0	1927.944	417.2487	331.86119	47100	4.71E+13	5814	44.09
385223300	0	2077.052	452.7668	341.05774	70600	7.06E+13	7741	56.02
465109600	0	2305.153	499.6782	350.48212	107700	1.077E+14	10130	92.08
517348100	0	2565.794	559.6919	359.40246	153300	1.533E+14	12780	160.9
545685900	0	2748.008	635.7926	367.47058	204900	2.049E+14	15430	247.9
559745300	0	2821.259	730.0255	374.95656	248400	2.484E+14	18340	352.5
558366700	0	2807.665	841.5202	381.75309	315400	3.154E+14	22280	466.6
543481600	0	2721.972	963.8416	387.79905	376900	3.769E+14	28220	564.8
516273100	0	2598.51	1088.97	392.83192	439900	4.399E+14	35130	638.5

Coal capacity	Concentrated solar capacity	Gas capacity	Geothermal capacity	Hydropower capacity	Nuclear capacity	Offshore wind capacity	Oil capacity	Onshore wind capacity	Other electricity capacity
967.1142	0.408451	1011.006		871.2293	403.097	0.6842	405.4771	58.03196	9.507541
1139.278	1.256	1170.674		1028.111	422.7627	3.1927	434.5956	193.142	11.24127
1089.114	8.269087	1616.254		1314.283	452.0645	19.43807	325.0383	470.4211	16.97595
871.7687	18.59721	1469.245		1430.762	452.4573	51.14825	248.7839	476.0843	27.49336
254.4913	577.3639	1072.343		1729.524	372.9538	467.2583	31.34222	1022.322	87.54459
209.9185	1978.521	1551.947		1820.346	213.9031	900.5343	8.938429	1986.75	136.447
268.0568	3690.9	2139.423		1876.622	184.2755	877.3956	7.83784	2112.915	181.4908
346.0633	5178.58	2639.027		1936	185.4034	655.3264	8.124931	1643.717	225.5976
336.2973	5959.577	2657.411		1990.567	236.2574	777.0181	7.283624	1608.656	270.6856
282.6755	6356.646	2253.057		2050.245	304.9577	930.3728	6.159712	1890.414	316.622
192.8441	6203.701	1886.382		2077.708	305.6004	776.3416	4.787603	1790.889	360.1929
967.1142	0.408451	1011.006		871.2293	403.097	0.6842	405.4771	58.03196	9.507541
1145.203	1.256	1167.242		1028.111	422.7627	3.1927	434.7843	193.142	11.24127
1358.195	6.389296	1672.53		1341.036	448.1711	19.43218	332.0894	445.4367	18.18246
1331.024	72.76783	2399.909		1576.637	453.498	187.5738	259.5569	647.1627	46.37654
1204.439	498.1575	2752.862		1751.807	347.1891	539.5996	136.7585	861.1098	90.33232
921.2822	1814.396	3040.355		1819.31	172.8064	766.6543	13.29367	1383.281	136.3408
741.3165	3648.462	3017.214		1878.782	129.6688	728.8048	3.984897	1987.364	181.4908
878.2613	5434.34	2847.3		1937.316	107.402	781.8494	3.345448	2109.278	226.356
891.9902	6388.975	2601.152		1987.437	117.5619	960.0585	2.673737	1859.289	271.547
806.116	6350.846	2354.686		2035.21	129.6582	907.529	0.981908	1539.682	316.0923
591.6446	7605.267	2397.229		2082.507	143.3619	818.3722	0.854149	1746.18	359.2863
967.1142	0.408451	1011.006		871.2293	403.097	0.6842	405.4771	58.03196	9.507541
1146.435	1.256	1166.455		1028.111	422.7627	3.1927	434.8128	193.142	11.24127
1421.552	5.790864	1683.2		1345.819	447.8269	17.94565	333.4576	444.6097	18.47044
1641.942	31.20054	2612.443		1577.071	442.6673	132.1734	260.0466	634.9364	46.37866
1744.23	198.3817	3375.869		1761.819	318.1085	510.4467	143.0688	886.0544	91.35909
1657.212	839.5912	4099.308		1820.837	140.3747	883.5641	37.39004	1428.04	136.447
1471.734	2455.441	4406.71		1878.782	92.9352	922.4809	11.79861	1732.065	181.4908
1431.351	4782.221	4116.567		1938.363	62.08425	905.1321	4.967896	2153.686	226.5345
1333.285	6509.652	3517.23		1993.917	44.93508	1064.435	2.994906	2328.328	271.3307
1142.411	6642.047	2817.367		2054.18	52.49417	1088.671	1.132294	2101.093	316.612
898.6857	6850.805	2491.775		2102.164	63.37466	953.7917	0.612264	2003.075	361.3211
967.1142	0.408451	1011.006		871.2293	403.097	0.6842	405.4771	58.03196	9.507541
1146.605	1.256	1166.355		1028.111	422.7627	3.1927	434.815	193.142	11.24127
1425.103	5.724216	1689.812		1345.791	447.8122	17.72753	333.5298	444.3717	18.46897
1736.052	25.62778	2611.211		1577.071	441.2135	117.1069	257.7094	624.5008	46.37866

2111.587	124.8312	3484.248		1762.228	311.5723	457.749	138.3481	857.6037	91.40331
2393.073	392.068	4286.645		1820.837	128.0851	834.1014	38.99168	1360.553	136.447
2516.338	1080.582	4807.685		1878.782	76.89836	935.0019	13.57557	1644.444	181.4908
2391.468	3044.718	4848.693		1938.363	39.39815	919.9186	5.80416	1848.747	226.5345
2061.766	5314.862	4533.64		1997.33	16.88613	1020.423	2.90736	2200.557	271.5308
1723.058	6391.279	4181.814		2057.524	22.32142	1144.029	1.453064	2394.093	316.622
1214.296	6688.285	4036.84		2117.105	23.41139	1026.929	0.728066	2376.649	361.6658
967.1142	0.408451	1011.006		871.2293	403.097	0.6842	405.4771	58.03196	9.507541
1146.618	1.256	1166.347		1028.111	422.7627	3.1927	434.8152	193.142	11.24127
1426.399	5.700469	1689.515		1346.035	447.812	17.63592	333.5559	444.2523	18.48137
1757.47	24.32383	2608.681		1577.071	441.0693	112.6597	256.8643	621.1443	46.37866
2208.786	111.5134	3511.657		1762.228	310.2281	439.85	132.2743	855.3053	91.40331
2571.693	328.4404	4310.247		1820.837	126.0087	809.5539	39.43519	1340.192	136.447
2912.966	773.2396	4857.325		1878.782	73.89302	910.8605	13.82658	1591.858	181.4908
3194.92	2013.003	5031.552		1938.363	34.46153	887.9611	5.743623	1777.796	226.5345
3227.006	3982.155	4950.68		1997.943	9.460465	943.8033	2.562412	2044.96	271.5783
3015.137	5309.353	4790.264		2057.524	8.444734	886.9701	1.149439	2195.256	316.622
2533.823	5646.774	4749.764		2117.105	5.751502	752.1234	0.522635	2267.013	361.6658
1208.495	0.3	891.075	9.764	855.358	405.859	0	408.377	55.351	
1553.732	1.731	1065.488	16.075	1127.523	415.13	0	233.178	254.922	
1613.275	1.731	1774.296	14.721	1225.253	510.583	0	87.756	653.669	
1175.07	12.206	2133.945	36.193	1634.296	762.768	73.833	45.119	2108.952	
477.651	56.152	2605.065	112.055	2123.571	1248.415	292.998	18.577	4425.197	
103.439	153.781	2538.66	167.891	2341.763	2243.648	647.958	10.681	6072.239	
38.937	341.217	2270.977	219.476	2555.453	3658.643	868.073	10.285	7724.418	
15.657	658.858	1573.546	270.27	2680.816	4459.27	1183.026	0.645	10058.44	
5.265	1119.525	1480.223	278.07	2749.172	4604.702	1519.714	0.001	12830.54	
1.24	1760.21	1502.834	287.276	2795.207	4151.388	2332.063	0.001	15122.17	
0.03	2706.043	1792.994	295.515	2825.668	3285.822	3479.677	0	17783.77	
1208.581	0.3	886.675	9.761	855.159	405.859	0	408.458	55.668	
1551.226	1.731	1064.809	16.072	1127.334	415.13	0	232.871	255.239	
1615.484	1.731	1773.927	14.718	1225.067	517.699	0	87.774	652.475	
1146.576	1.581	2861.203	8.783	1467.604	705.903	14.726	45.109	1542.215	
481.693	0	4214.792	14.761	1637.852	995.004	82.783	18.924	2433.376	
158.12	11.44	5277.666	25.741	2010.801	1616.659	153.766	10.703	3528.955	
151.718	49.886	5588.482	39.126	2220.299	2527.999	160.448	10.285	4913.721	
140.467	140.368	5506.158	68.915	2460.321	3549.061	194.403	0.645	6696.389	
93.673	309.329	4655.599	143.09	2645.272	4178.811	474.502	0.001	9812.325	
78.942	604.81	4267.885	218.133	2788.212	4476.083	996.11	0.001	14154.4	
65.34	1076.35	3711.095	284.64	2826.235	4275.281	2427.28	0	18583.07	
1208.581	0.3	886.675	9.761	855.159	405.859	0	408.458	55.668	
1551.259	1.731	1064.776	16.072	1127.331	415.13	0	232.871	255.239	
1614.296	1.731	1766.62	14.718	1219.116	517.692	0	87.774	648.413	
1173.583	1.581	2896.461	8.783	1316.548	515.831	0	45.109	1210.556	
486.978	0	4712.235	1.462	1616.08	595.585	0	18.924	2127.393	
124.407	0	6240.346	9.754	1733.223	898.287	0	10.704	3282.19	
120.289	0	7168.648	20.5	2042.709	1612.955	17.357	10.285	4521.637	

122.55	4.176	6780.278	33.588	2250.893	2848.424	26.941	0.645	5616.395
139.529	30.241	6860.963	58.393	2427.428	3953.613	80.617	0.001	6965.821
122.709	99.561	6652.435	103.285	2659.684	4638.2	254.855	0.001	10087.95
131.67	234.498	6221.054	187.828	2775.967	5133.383	715.742	0	14373.04
1208.581	0.3	886.675	9.761	855.159	405.859	0	408.458	55.668
1551.258	1.731	1064.78	16.072	1127.322	415.13	0	232.871	255.239
1615.257	1.731	1770.619	14.718	1219.107	517.672	0	87.774	586.564
1203.969	1.581	2957.59	8.392	1299.642	482.919	0	45.109	1197.518
660.908	0	4773.125	1.044	1569.448	453.548	0	18.924	1937.532
443.021	0	6415.364	1.044	1654.466	642.994	0	10.704	2900.356
361.409	0	8169.03	0.625	1757.112	1019.553	0	10.285	4336.712
209.818	0	9245.938	0.625	1913.975	1870.821	0	0.645	5505.533
66.886	0	8678.841	3.676	2219.417	3231.544	6.331	0.001	6338.78
106.755	5.911	6851.948	26.463	2551.319	4973.72	57.813	0.001	7312.789
162.155	21.012	7023.52	58.106	2651.798	5907.931	220.077	0	9773.232
1208.581	0.3	886.675	9.761	855.159	405.859	0	408.459	55.668
1551.244	1.731	1064.785	16.072	1127.322	415.13	0	232.871	255.239
1622.503	1.731	1785.881	14.718	1203.07	515.824	0	87.774	577.031
1305.72	1.581	2979.112	7.569	1285.545	443.409	0	45.109	1070.444
998.938	0	4738.963	0.552	1545.23	300.53	0	18.924	1627.025
1003.563	0	6410.777	0.552	1602.527	243.48	0	10.704	2537.575
1171.917	0	8364.108	0.33	1679.026	408.626	0	10.285	3798.951
1221.924	0	10508.69	0.198	1744.525	738.856	0	0.645	5229.015
932.452	0	11566.39	0.198	1808.327	1441.858	0	0.001	6584.746
613.012	0	12313.31	0.198	1880.185	2236.559	0	0.001	7574.665
180.631	3.6	12352.25	0.118	2461.538	3639.268	35.062	0	7932.377
1208.573	0.3	886.682	9.761	855.159	405.859	0	408.459	55.668
1551.261	1.731	1065.357	16.072	1127.322	415.13	0	232.871	255.239
1633.631	1.731	1776.817	14.718	1219.093	510.503	1.397	87.775	539.355
1400.377	1.581	2938.788	7.348	1299.642	437.005	1.397	45.109	930.896
1246.33	0	4651.492	0	1449.456	280.877	1.397	18.924	1417.627
1401.864	0	6273.41	0	1496.386	164.578	1.397	10.704	2120.488
1793.776	0	8174.206	0	1559.967	216.564	1.397	10.285	3132.977
2188.913	0	10345.67	0	1660.99	379.041	1.397	0.645	4360.887
2618.646	0	11573.9	0	1771.369	670.335	0	0.001	5090.801
2695.971	0	12595.77	0	1830.528	1171.696	0	0.001	6253.277
2397.212	0	14291.69	0	1847.502	1765.228	17.531	0	7932.747
1336.707		604.4403	8.7966	826.382	446.4509		188.9644	35.3325
1558.797		661.1185	9.1906	947.0204	457.5221		213.0637	43.2872
1906.579		786.1355	10.8795	1217.501	573.113		263.429	106.4602
1866.045		897.294	12.5576	1499.603	853.5622		282.1999	434.5027
1086.447		867.5611	14.4541	2028.14	971.7501		327.0354	1107.792
1120.694		819.178	16.071	2157.197	827.6001		312.2426	1674.147
1293.82		802.2418	17.4926	2234.432	662.012		293.2141	2486.241
1045.381		731.62	18.8817	2443.697	633.5754		266.1866	3793.876
853.6205		659.7239	20.2102	2520.373	635.6717		245.1536	5281.18
684.5843		551.9451	21.5337	2520.373	626.3032		211.284	7135.913

542.5672	456.8641	22.9643	2520.373	602.2237	176.7628	9049.08
1336.707	604.4403	8.7966	826.382	446.4509	188.9644	35.3325
1558.797	661.1185	9.1906	947.0204	457.5221	213.0637	43.2872
1906.579	786.1355	10.8795	1217.501	573.113	263.429	106.4602
2133.929	854.0991	12.351	1498.876	851.9775	284.6063	311.8137
1655.461	879.0911	13.9336	1886.333	951.9803	335.1781	657.2819
1431.409	772.7874	15.5165	2097.747	884.3293	294.7325	1054.178
1398.621	666.0965	16.928	2243.608	796.7804	242.9729	1730
1424.974	675.7736	18.3115	2349.351	690.3162	245.9421	2341.542
1461.077	671.9053	19.6445	2424.754	627.5396	248.9704	3163.73
1415.127	651.6144	20.9754	2485.822	592.1114	248.8693	4336.894
1238.569	606.2031	22.4136	2520.373	598.9519	241.2031	5902.378
1336.707	604.4403	8.7966	826.382	446.4509	188.9644	35.3325
1558.797	661.1185	9.1906	947.0204	457.5221	213.0637	43.2872
1906.579	786.1355	10.8795	1217.501	573.113	263.429	106.4602
2162.3	850.3594	12.297	1498.826	851.8702	284.4476	304.5432
2068.143	880.905	13.6695	1772.887	900.4445	329.1332	563.8515
2029.085	853.2133	15.1108	1979.838	761.259	317.9447	821.7309
2133.272	783.5704	16.4944	2037.209	596.7124	281.2418	1127.665
1867.118	695.7149	17.8686	2184.176	527.3379	257.9778	1516.401
1854.448	612.0258	19.2029	2282.791	479.7949	234.1682	2060.77
2093.876	571.7496	20.5408	2334.624	411.532	225.8197	2656.928
2332.247	539.2225	21.9881	2354.653	360.799	215.9976	3387.528
1336.707	604.4403	8.7966	826.382	446.4509	188.9644	35.3325
1571	661.892	9.194	937.6342	449.3162	213.0396	43.4013
2110.059	783.6254	10.9682	1159.794	524.5556	263.8251	57.1599
2791.207	940.2569	12.7537	1316.08	592.5745	312.7029	75.2413
3496.536	1052.656	14.5341	1528.463	575.1862	357.2171	95.8726
4309.221	1165.433	16.1714	1859.332	494.9324	375.3293	114.2928
5048.089	1188.251	17.6472	2076.555	409.7721	365.6244	153.5991
5868.657	1147.202	19.0954	2159.64	342.2928	368.849	200.2114
6715.017	1096.278	20.5016	2237.118	283.2221	368.2831	269.4603
7610.444	1049.907	21.9155	2283.161	236.0092	381.2876	349.4753
8586.262	1005.416	23.4492	2296.368	206.137	375.2147	450.7418

1225.958	841.2101	9.716098	349.6053	1085.217	0
1693.754	1140.513	67.0341	510.8682	360.6318	0
1228.808	1243.012	166.622	1530.018	253.1453	0
1073.495	1254.237	204.1142	2413.031	129.1626	0
1071.386	1216.835	223.4281	3153.946	68.90377	0
931.6911	1224.682	231.3622	3905.114	49.13613	0
628.7336	1106.922	233.9821	4587.919	49.56565	0
233.7913	801.3357	231.6631	5183.68	67.5284	0
50.59647	458.0889	230.0954	5109.573	99.44499	0
8.568845	148.5998	180.6275	4893.532	63.78672	0
1225.958	841.2101	9.716106	349.6053	1085.217	0

1693.754	1140.513	67.0341	510.8682	360.6322	0
1716.053	1293.324	139.5919	1008.812	305.8904	0
1345.413	1369.899	182.9874	1846.324	202.3471	0
1006.978	1318.441	207.8897	2701.807	121.6	0
920.5796	1135.353	220.7376	3367.095	77.61129	0
804.8737	1023.967	222.8477	4024.203	49.01813	0
633.9834	937.3923	217.0962	4541.143	44.37575	0
302.3548	720.81	210.888	4839.151	53.88509	0
74.31952	442.4846	199.5887	4794.77	77.12468	0
1225.958	841.2101	9.716106	349.6053	1085.217	0
1693.754	1140.513	67.0341	510.8682	360.6322	0
1846.253	1331.803	128.3021	853.4231	328.418	0
1737.86	1426.401	165.1665	1432.186	230.208	0
1325.98	1432.084	190.7936	2202.566	155.2775	0
934.0023	1214.835	210.5004	2947.221	125.6095	0
782.0435	994.6936	217.2496	3598.212	73.38565	0
689.3045	900.2817	198.5876	3875.422	49.57959	0
637.6053	806.0891	181.7046	4024.789	55.17809	0
532.3713	693.9291	171.8699	4050.719	45.52628	0
1225.958	841.2101	9.716106	349.6053	1085.217	0
1693.754	1140.513	67.0341	510.8682	360.6322	0
2014.376	1395.452	115.6949	727.4788	369.4773	0
2139.452	1536.954	141.358	1042.492	272.6893	0
2160.038	1612.299	150.9597	1360.336	199.7782	0
2150.953	1416.25	157.194	1657.732	208.2219	0
2102.007	1218	161.1226	1974.2	176.1341	0
1592.537	1102.254	171.7487	2391.867	173.2052	0
1035.827	978.3102	174.6699	2804.311	170.1273	0
501.7329	848.5339	170.2217	3150.743	129.49	0
1031.966	631.8461	8.304925	351.0846	1239.128	
1225.958	841.2101	9.716106	349.6053	1085.217	
1748.912	1187.257	64.68386	481.8749	432.9278	
2085.85	1435.85	112.3128	698.3523	397.5347	
2239.666	1598.721	136.5254	985.0269	307.3984	
2297.31	1696.712	144.5328	1261.837	232.3134	
2326.558	1527.514	148.3682	1508.224	250.9439	
2349.912	1332.252	147.6353	1750.521	222.5091	
1962.312	1251.47	151.7688	2031.551	234.5549	
1681.387	1175.393	149.1296	2191.384	247.3909	
1453.393	1166.226	141.6507	2238.914	235.0923	
1134	0	925.2	7.727	702.4	400.9
1299	0.53	1147	11.55	743.3	403.7
1297	4.427	2241	14.31	702.1	481.9
650.4	66.08	2761	33.26	890.5	830.6
134.4	684.5	1752	42.76	2105	1627

0.5999	3009	1165	43.19	3539	2295
0.2419	6551	730.5	42.26	4102	2659
0.0664	9700	383.8	40.25	4326	2854
0.0826	12420	150.4	39.48	4515	2809
0.089	15000	84.77	39.3	4683	2662
0.0777	17940	45.36	39.46	4798	2485
1134	0	925.2	7.727	702.4	400.9
1299	0.53	1147	11.55	743.3	403.7
1297	4.427	2241	14.31	702.1	481.9
705.5	12.25	4062	28.5	750.4	681.5
187.1	116.1	4742	38.83	1277	1159
2.116	737	4367	42.28	2403	1894
1.084	2674	3793	43.41	3483	2501
0.601	5964	2841	42.9	4084	2890
0.3086	10050	1375	42.32	4288	3018
0.1041	13850	581.3	41.11	4390	2799
0.0772	16980	302.8	40.33	4475	2500
1134	0	925.2	7.727	702.4	400.9
1299	0.53	1147	11.55	743.3	403.7
1297	4.427	2241	14.31	702.1	481.9
827.5	5.07	4448	27.05	705.6	615.4
329	24.87	6057	36.38	987.6	881.8
103.4	208.9	6566	40.21	1762	1356
41.39	1074	6481	42.27	2745	1920
32.71	3383	5398	43.41	3585	2464
19.61	7306	3399	43.41	4100	2888
7.433	11640	1470	42.89	4277	2935
6.648	15280	826.4	43.41	4354	2645
1134	0	925.2	7.727	702.4	400.9
1299	0.53	1147	11.55	743.3	403.7
1297	4.427	2241	14.31	702.1	481.9
882.8	4.449	4444	26.59	696.8	606.5
484.5	9.686	6128	35.54	929.2	848.6
356.9	79.89	6801	39.47	1598	1307
285.6	485.9	6545	41.62	2448	1880
275.1	1782	5876	43.07	3164	2341
274	4345	4733	43.41	3744	2654
294.4	7587	3308	42.93	4080	2703
366.9	10330	2351	43.41	4209	2492
1134	0	925.2	7.727	702.4	400.9
1299	0.53	1147	11.55	743.3	403.7
1297	4.427	2241	14.31	702.1	481.9
1255	4.25	4364	24.53	663	545.8
1188	4.001	6536	32.5	742.3	632.8
1089	13.13	8096	37.9	1132	880.7
981.1	103	8132	40.75	1866	1396
787.7	477.8	6937	42.44	2537	2178

638.7	1517	5343	43.41	3132	2973
640.7	3668	3864	43.16	3741	3259
638.1	6746	2478	43.41	4214	3012
1134	0	925.2	7.727	702.4	400.9
1299	0.53	1147	11.55	743.3	403.7
1577	4.427	2027	12.73	688.8	480.8
2231	4.25	3415	17.68	610.6	487.5
3262	3.219	5041	23.12	564.3	425.6
4381	1.778	6260	31.25	638.7	348.6
5449	7.336	6718	35.64	956.4	246.4
6210	46.87	6798	38.54	1540	203.6
6476	223.7	6654	40.95	2193	383.1
6202	788.4	6056	42.26	2640	763.2
5519	2056	4878	43.41	3011	1304

Solar capacity	Solar PV capacity	Wind capacity	Black carbon emissions	Methane emissions	Fossil methane emissions	Land methane emissions	Carbon monoxide emissions	CO2 emissions
4.902305	4.493854	58.71616	10166850	3.18E+08		1.54E+08	NaN	33166074220
40.07435	38.81835	196.3347	10420980	3.48E+08		1.64E+08	NaN	35488828780
287.0316	278.7625	489.8592	7281273	3E+08		1.53E+08	NaN	33208799480
404.7742	386.177	527.2326	3990174	2.15E+08		1.23E+08	NaN	17967968260
2934.135	2356.771	1489.58	3308903	1.79E+08		1.06E+08	NaN	6413946208
4996.537	3018.016	2887.284	2538134	1.53E+08		86351827	NaN	968036255
6170.391	2479.491	2990.311	2308984	1.44E+08		82002647	NaN	-1649998545
6299.851	1121.271	2299.043	2174113	1.36E+08		78378320	NaN	-4136923829
7206.669	1247.092	2385.674	2040057	1.26E+08		74407122	NaN	-7370205445
7876.061	1519.415	2820.787	1907362	1.17E+08		70342212	NaN	-10567707520
7878.032	1674.331	2567.231	1797451	1.1E+08		66408749	NaN	-14340424640
4.902305	4.493854	58.71616	10166850	3.18E+08		1.54E+08	NaN	33166074220
40.07435	38.81835	196.3347	10420980	3.48E+08		1.64E+08	NaN	35488821620
254.8332	248.4439	464.8689	7713113	3.15E+08		1.53E+08	NaN	38389781580
659.4355	586.6677	834.7365	4706756	2.57E+08		1.33E+08	NaN	33930925130
2162.961	1664.803	1400.709	3825954	2.2E+08		1.11E+08	NaN	25904736820
4640.146	2825.75	2149.935	3227433	1.9E+08		92485721	NaN	17732934570
6474.691	2826.229	2716.169	2945252	1.75E+08		87122877	NaN	10565807940
7558.562	2124.222	2891.127	2767615	1.57E+08		83303713	NaN	4785242147
8098.997	1710.022	2819.348	2417529	1.35E+08		76434132	NaN	-2921840088
8053.079	1702.233	2447.211	2236856	1.28E+08		72927185	NaN	-8098321208
10154.25	2548.979	2564.552	1934944	1.2E+08		68847568	NaN	-8347350180
4.902305	4.493854	58.71616	10166850	3.18E+08		1.54E+08	NaN	33166074220
40.07435	38.81835	196.3347	10420980	3.48E+08		1.64E+08	NaN	35488818040
254.2848	248.4939	462.5553	7821450	3.54E+08		1.6E+08	NaN	39638793620
566.0787	534.8782	767.1098	4998291	3.09E+08		1.41E+08	NaN	39351400720
1674.526	1476.144	1396.501	4199383	2.69E+08		1.3E+08	NaN	37443119140
4245.226	3405.635	2311.604	3495168	2.39E+08		1.15E+08	NaN	32947266600
6727.268	4271.827	2654.546	3211494	2.15E+08		1.06E+08	NaN	27955583340
8742.543	3960.322	3058.818	2924976	1.79E+08		88706014	NaN	19813280930
9592.789	3083.137	3392.763	2534620	1.55E+08		80541286	NaN	9123370281
9160.915	2518.868	3189.764	2234435	1.35E+08		75176611	NaN	-2275437907
9642.938	2792.133	2956.867	2142955	1.31E+08		74410852	NaN	-6615458456
4.902305	4.493854	58.71616	10166850	3.18E+08		1.54E+08	NaN	33166074220
40.07435	38.81835	196.3347	10420980	3.48E+08		1.64E+08	NaN	35488818040
253.9978	248.2736	462.0992	7894477	3.58E+08		1.62E+08	NaN	39860114910
543.5984	517.9706	741.6077	5238015	3.31E+08		1.44E+08	NaN	40958095380

1461.163	1336.332	1315.353	4443136	3.12E+08	1.36E+08	NaN	41498599290
3629.455	3237.387	2194.654	3655778	2.98E+08	1.25E+08	NaN	40020968430
5968.284	4887.702	2579.446	3274412	2.66E+08	1.19E+08	NaN	37734730150
8790.074	5745.356	2768.666	2991351	2.29E+08	1.13E+08	NaN	32323002280
10580.37	5265.504	3220.98	2611052	1.91E+08	1.03E+08	NaN	24455647950
10931.2	4539.917	3538.122	2274801	1.62E+08	89280899	NaN	17307671060
10630.27	3941.984	3403.578	1954180	1.4E+08	77464208	NaN	11079046390
4.902305	4.493854	58.71616	10166850	3.18E+08	1.54E+08	NaN	33166074220
40.07435	38.81835	196.3347	10420980	3.48E+08	1.64E+08	NaN	35488818040
253.8592	248.1587	461.8882	7955021	3.66E+08	1.64E+08	NaN	40069003910
537.767	513.4432	733.804	5752160	3.81E+08	1.63E+08	NaN	42653234050
1412.255	1300.742	1295.155	4851265	3.9E+08	1.58E+08	NaN	43778496100
3444.046	3115.606	2149.746	3782655	3.8E+08	1.48E+08	NaN	42454757820
5616.793	4843.553	2502.719	3271831	3.62E+08	1.41E+08	NaN	41601928390
8186.35	6173.347	2665.757	3005288	3.39E+08	1.38E+08	NaN	39217531580
10594.35	6612.197	2988.763	2631899	3.05E+08	1.36E+08	NaN	33392293950
11387.18	6077.83	3082.226	2260235	2.73E+08	1.32E+08	NaN	28618413900
10981.92	5335.141	3019.136	1972020	2.46E+08	1.29E+08	NaN	24612913580
3.7	3.4	55.351	6897883	3.34E+08	1.47E+08	NaN	37767241830
39.781	38.05	254.922	7033091	3.26E+08	1.5E+08	NaN	40313502030
259.191	257.46	653.669	5953591	3.3E+08	1.52E+08	NaN	40931321740
1239.157	1226.951	2182.785	5042782	2.68E+08	1.51E+08	NaN	23633128530
2544.946	2488.794	4718.195	4466717	2.2E+08	1.32E+08	NaN	11524129400
4807.605	4653.824	6720.197	3953877	1.92E+08	1.16E+08	NaN	3778922018
7292.842	6951.625	8592.491	3492772	1.69E+08	1.02E+08	NaN	-1510684608
10635.17	9976.307	11241.47	2978596	1.47E+08	92033232	NaN	-6540368386
12784.66	11665.13	14350.26	2456218	1.27E+08	83271741	NaN	-10608864180
15765.84	14005.63	17454.23	2022746	1.13E+08	75616620	NaN	-12410880580
20556.68	17850.64	21263.45	1882179	1.03E+08	68898560	NaN	-13048889880
3.7	3.4	55.668	6897921	3.34E+08	1.47E+08	NaN	37770820260
39.781	38.05	255.239	7032949	3.27E+08	1.5E+08	NaN	40294322570
259.181	257.45	652.475	5962082	3.31E+08	1.51E+08	NaN	40656969190
360.494	358.913	1556.941	5395076	3.08E+08	1.6E+08	NaN	34541602380
823.885	823.885	2516.159	4814379	2.7E+08	1.53E+08	NaN	26305611870
1959.471	1948.031	3682.721	4197154	2.44E+08	1.42E+08	NaN	16330601410
3538.011	3488.125	5074.169	3649116	2.26E+08	1.29E+08	NaN	9247853483
6197.911	6057.543	6890.792	3129527	2.18E+08	1.18E+08	NaN	2010280498
9116.889	8807.56	10286.83	2652950	2E+08	1.08E+08	NaN	-4045766822
13017.6	12412.79	15150.51	2214105	1.76E+08	98074308	NaN	-6495753010
19097.87	18021.52	21010.35	2041940	1.56E+08	89623261	NaN	-8357277098
3.7	3.4	55.668	6897921	3.34E+08	1.47E+08	NaN	37770833690
39.781	38.05	255.239	7032939	3.27E+08	1.5E+08	NaN	40294283120
259.181	257.45	648.413	5954571	3.33E+08	1.54E+08	NaN	41685860990
290.108	288.527	1210.556	5551665	3.37E+08	1.66E+08	NaN	42031556660
507.87	507.87	2127.393	5092204	3.02E+08	1.62E+08	NaN	38219667350
1138.34	1138.34	3282.19	4528868	2.78E+08	1.56E+08	NaN	32611938560
2433.64	2433.64	4538.994	3926427	2.57E+08	1.47E+08	NaN	24302660540

3951.654	3947.478	5643.336	3280636	2.49E+08	1.38E+08	NaN	15423403940
5660.827	5630.586	7046.438	2686918	2.43E+08	1.27E+08	NaN	7974427459
8966.094	8866.533	10342.8	2356392	2.31E+08	1.17E+08	NaN	1860016865
12294.81	12060.32	15088.78	2305570	2.12E+08	1.06E+08	NaN	-1418092488
3.7	3.4	55.668	6897921	3.34E+08	1.47E+08	NaN	37770827990
39.781	38.05	255.239	7032940	3.27E+08	1.5E+08	NaN	40294293820
259.181	257.45	586.564	5950466	3.36E+08	1.55E+08	NaN	42284928730
267.815	266.234	1197.518	5587177	3.47E+08	1.67E+08	NaN	44385654470
365.293	365.293	1937.532	5162646	3.32E+08	1.71E+08	NaN	44491570780
670.059	670.059	2900.356	4620340	3.12E+08	1.67E+08	NaN	42832156140
1317.231	1317.231	4336.712	4176487	2.91E+08	1.6E+08	NaN	39042389740
2692.117	2692.117	5505.533	3639191	2.81E+08	1.52E+08	NaN	34193217950
4044.339	4044.339	6345.111	3016475	2.69E+08	1.44E+08	NaN	25823818090
6636.43	6630.519	7370.602	2425261	2.62E+08	1.34E+08	NaN	15468528590
8900.084	8879.072	9993.309	2190230	2.57E+08	1.23E+08	NaN	9115046702
3.7	3.4	55.668	6897921	3.34E+08	1.47E+08	NaN	37770773340
39.781	38.05	255.239	7032940	3.27E+08	1.5E+08	NaN	40294276410
259.181	257.45	577.031	5955364	3.39E+08	1.57E+08	NaN	42392228060
260.893	259.312	1070.444	5639539	3.62E+08	1.68E+08	NaN	46125215530
274.78	274.78	1627.025	5243723	3.73E+08	1.76E+08	NaN	49544828530
311.474	311.474	2537.575	4745865	3.68E+08	1.8E+08	NaN	52585738920
666.343	666.343	3798.951	4324438	3.54E+08	1.78E+08	NaN	54663549370
1471.99	1471.99	5229.015	3780013	3.46E+08	1.74E+08	NaN	55537153420
2648.202	2648.202	6584.746	3287629	3.27E+08	1.69E+08	NaN	55974066830
4307.712	4307.712	7574.665	2840070	3.15E+08	1.61E+08	NaN	56218816630
5843.083	5839.483	7967.439	2592205	2.9E+08	1.53E+08	NaN	55426330740
3.7	3.4	55.668	6897915	3.34E+08	1.47E+08	NaN	37768994360
39.781	38.05	255.239	7032933	3.27E+08	1.5E+08	NaN	40294638280
259.181	257.45	540.752	5989514	3.45E+08	1.58E+08	NaN	42262425250
257.331	255.75	932.293	5669987	3.73E+08	1.69E+08	NaN	46727550650
238.229	238.229	1419.024	5271352	3.93E+08	1.77E+08	NaN	51606451500
159.66	159.66	2121.885	4853472	4.11E+08	1.83E+08	NaN	56651629190
382.054	382.054	3134.374	4443642	4.26E+08	1.87E+08	NaN	61402269010
899.171	899.171	4362.284	3947394	4.33E+08	1.88E+08	NaN	65996979000
1335.941	1335.941	5090.801	3434581	4.36E+08	1.87E+08	NaN	74133629280
2096.954	2096.954	6253.277	2952570	4.34E+08	1.87E+08	NaN	81028376880
3374.932	3374.932	7950.278	2717675	4.22E+08	1.86E+08	NaN	85684204390
1.2895	1.2895	35.3325	8334800	3.5E+08	1.7E+08	NaN	34373934500
11.877	11.877	43.2872	7903800	3.76E+08	1.85E+08	NaN	39398615600
26.7852	26.7852	106.4602	8340500	4.24E+08	2.15E+08	NaN	46637736200
134.9159	134.9159	434.5027	8348000	4.58E+08	2.42E+08	NaN	48292181400
590.6526	590.6526	1107.792	6578600	3.43E+08	2.09E+08	NaN	32552846300
1230.742	1230.742	1674.147	6182300	2.94E+08	2E+08	NaN	22930895200
1836.412	1836.412	2486.241	5798800	3.01E+08	2.1E+08	NaN	16754039300
2650.958	2650.958	3793.876	5327600	2.96E+08	2.14E+08	NaN	9494704600
3895.256	3895.256	5281.18	4959700	2.94E+08	2.18E+08	NaN	3925184500
5353.665	5353.665	7135.913	4670700	2.93E+08	2.23E+08	NaN	-713415000

7078.745	7078.745	9049.08	4462100	2.94E+08	2.27E+08	NaN	-3861942700
1.2895	1.2895	35.3325	8334800	3.5E+08	1.7E+08	NaN	34373934500
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26.7852	26.7852	106.4602	8340500	4.24E+08	2.15E+08	NaN	46637736200
102.2534	102.2534	311.8137	8385700	4.68E+08	2.44E+08	NaN	50589140800
335.3812	335.3812	657.2819	7293100	3.73E+08	2.26E+08	NaN	43026225700
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1276.55	1276.55	1730	6157400	3.37E+08	2.26E+08	NaN	25470368300
1694.822	1694.822	2341.542	5824900	3.45E+08	2.36E+08	NaN	19713865200
2210.791	2210.791	3163.73	5447000	3.51E+08	2.46E+08	NaN	15958927700
3026.237	3026.237	4336.894	5073700	3.52E+08	2.53E+08	NaN	11400028500
4249.112	4249.112	5902.378	4735100	3.47E+08	2.55E+08	NaN	6401836300
1.2895	1.2895	35.3325	8334800	3.5E+08	1.7E+08	NaN	34373934500
11.877	11.877	43.2872	7903800	3.76E+08	1.85E+08	NaN	39398615600
26.7852	26.7852	106.4602	8340500	4.24E+08	2.15E+08	NaN	46637736200
100.3114	100.3114	304.5432	8388600	4.7E+08	2.45E+08	NaN	50805267700
282.7516	282.7516	563.8515	7713300	4.08E+08	2.39E+08	NaN	48074469800
573.4055	573.4055	821.7309	7336600	3.93E+08	2.4E+08	NaN	46888112200
822.4284	822.4284	1127.665	7000600	4.2E+08	2.6E+08	NaN	48048435800
1105.647	1105.647	1516.401	6500800	4.24E+08	2.7E+08	NaN	43526677200
1496.907	1496.907	2060.77	6002100	4.29E+08	2.81E+08	NaN	37554195400
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2349.263	2349.263	3387.528	5250600	4.53E+08	3.04E+08	NaN	31248202100
1.2895	1.2895	35.3325	8334800	3.5E+08	1.7E+08	NaN	34373934500
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19.4	19.4	57.1599	8366100	4.36E+08	2.19E+08	NaN	48502706900
33.1709	33.1709	75.2413	8392600	4.9E+08	2.49E+08	NaN	55000886500
53.8618	53.8618	95.8726	8478400	5.34E+08	2.75E+08	NaN	59877305400
81.5896	81.5896	114.2928	8160500	5.75E+08	2.99E+08	NaN	64001363000
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139.5087	139.5087	200.2114	7169500	6.55E+08	3.46E+08	NaN	71792665700
186.9195	186.9195	269.4603	6686300	6.95E+08	3.69E+08	NaN	75571458400
241.6192	241.6192	349.4753	6254300	7.34E+08	3.91E+08	NaN	80137183400
309.9962	309.9962	450.7418	5842600	7.74E+08	4.13E+08	NaN	85214965500
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209.0308		404.5147	7466236	3.94E+08	1.98E+08	1.96E+08 NaN	40048785360
587.7284		1277.995	6513433	3.45E+08	1.39E+08	2.05E+08 NaN	23821810490
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2087.153		2398.587	6135944	3.57E+08	1.2E+08	2.38E+08 NaN	11881383240
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18.78684		92.8781	7718361	3.68E+08	1.93E+08	1.75E+08 NaN	35775762490

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2947.763	2305.174	5562365	3.8E+08	1.23E+08	2.57E+08	NaN	14798745000	
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18.78684	92.8781	7718361	3.68E+08	1.93E+08	1.75E+08	NaN	35775762450	
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463.2488	781.4397	7031678	3.84E+08	1.7E+08	2.14E+08	NaN	39451086240	
944.7735	1274.394	6755184	4.04E+08	1.7E+08	2.34E+08	NaN	36566084270	
1705.505	1721.088	6270053	4.03E+08	1.51E+08	2.52E+08	NaN	29034578190	
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2125.656	1243.843	6310183	4.79E+08	1.91E+08	2.88E+08	NaN	47612523330	
2923.487	1357.16	5629815	4.75E+08	1.74E+08	3.01E+08	NaN	44591015670	
3674.966	1650.892	4864903	4.63E+08	1.52E+08	3.11E+08	NaN	36805763550	
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395.3757	647.3734	7746030	4.78E+08	2.53E+08	2.25E+08	NaN	49069570240	
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2705.515	1179.41	5903478	5.75E+08	2.62E+08	3.13E+08	NaN	55898208470	
3307.738	1357.156	5161018	5.7E+08	2.4E+08	3.3E+08	NaN	51172922990	
3810.335	1502.615	4485016	5.68E+08	2.24E+08	3.44E+08	NaN	47532718760	
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1.053	1.053	39.69	6741900	3.34E+08	1.06E+08	1.57E+08	NaN	35280000000
39.35	38.82	180.4	6625300	3.71E+08	1.22E+08	1.71E+08	NaN	36370000000
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1.053	1.053	39.69	6725500	3.34E+08	1.06E+08	1.57E+08	NaN	35229942500
39.35	38.82	180.4	6710000	3.71E+08	1.22E+08	1.72E+08	NaN	36335005000
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1.053	1.053	39.69	6725500	3.34E+08	1.06E+08	1.57E+08	NaN	35229942500
39.35	38.82	180.4	6710000	3.71E+08	1.22E+08	1.72E+08	NaN	36335005000
269.5	265.1	514.7	6410600	3.91E+08	1.24E+08	2.04E+08	NaN	39549850200
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1.053	1.053	39.69	6725500	3.34E+08	1.06E+08	1.57E+08	NaN	35229942500
39.35	38.82	180.4	6710000	3.71E+08	1.22E+08	1.72E+08	NaN	36335005000
269.5	265.1	514.7	6410600	3.91E+08	1.24E+08	2.04E+08	NaN	39542470000
255.8	251.3	788.3	5585500	3.83E+08	1.06E+08	2.23E+08	NaN	44934095600
236	226.3	1286	4788000	3.56E+08	83650000	2.31E+08	NaN	46002393100
547.5	467.6	2483	3842700	3.11E+08	64000000	2.17E+08	NaN	43224373000
2500	2014	4269	3471300	2.84E+08	53880000	2.08E+08	NaN	37171389900
6910	5128	6749	3103900	2.66E+08	45850000	1.98E+08	NaN	29477403200
14120	9778	10180	2842400	2.42E+08	36440000	1.82E+08	NaN	23649949400
22440	14850	14600	2609800	2.1E+08	25990000	1.61E+08	NaN	17166311100
29260	18930	17110	2405600	1.77E+08	20200000	1.33E+08	NaN	15860667200
1.053	1.053	39.69	6725500	3.34E+08	1.06E+08	1.57E+08	NaN	35229942500
39.35	38.82	180.4	6709000	3.71E+08	1.22E+08	1.72E+08	NaN	36335005000
269.5	265.1	514.7	6409600	3.91E+08	1.24E+08	2.04E+08	NaN	39560359500
254.6	250.3	705.8	5755800	4.15E+08	1.26E+08	2.28E+08	NaN	47835990100
188.9	184.9	907.5	5110500	4.23E+08	1.23E+08	2.45E+08	NaN	54512741600
142.5	129.3	1526	4171300	4.03E+08	1.15E+08	2.4E+08	NaN	58172971300
907.2	804.2	2643	3756600	3.66E+08	95480000	2.3E+08	NaN	58939778700
3600	3123	4705	3375400	3.26E+08	74720000	2.18E+08	NaN	55299005200

8851	7334	7843	3083300	2.77E+08	55720000	1.94E+08	NaN	50540137300
15930	12260	11840	2801300	2.36E+08	42720000	1.69E+08	NaN	44186311100
23160	16410	14150	2543100	2.02E+08	34390000	1.44E+08	NaN	40968865200
1.053	1.053	39.69	6741900	3.34E+08	1.06E+08	1.57E+08	NaN	35279640500
39.35	38.82	180.4	6624300	3.71E+08	1.22E+08	1.71E+08	NaN	36371124600
269.5	265.1	484.5	6682800	4.08E+08	1.21E+08	2.19E+08	NaN	44610389300
254.6	250.3	560.1	6081300	4.77E+08	1.4E+08	2.64E+08	NaN	56726452000
183.3	180.1	538.5	5474300	5.7E+08	1.86E+08	3.08E+08	NaN	69861617000
22.5	20.72	936.7	4490500	6.31E+08	2.1E+08	3.32E+08	NaN	84436466100
43.59	36.26	1736	4027200	6.45E+08	2.28E+08	3.36E+08	NaN	1.01302E+11
352.5	305.6	2845	3649000	6.46E+08	2.37E+08	3.31E+08	NaN	1.175E+11
1673	1449	4396	3356300	6.21E+08	2.3E+08	3.15E+08	NaN	1.29499E+11
5083	4295	6864	3016200	5.83E+08	2.24E+08	2.84E+08	NaN	1.30398E+11
10410	8353	9328	2683600	5.4E+08	2.05E+08	2.45E+08	NaN	1.26098E+11

CO2 emissions (BECCS)	CO2 emissions (CCS)	Fossil CO2 emissions	Land CO2 emissions	F-gas emissions	Kyoto gas emisison	Nitrous oxide emissions	Land nitrous oxide emissions
0	0	29394248380	3771829776	6.73E+08	4.45E+10	9156453	6874411
0	0	31981488160	3507338835	8.78E+08	4.8E+10	9831880	7486986
48300128.47	181468957.1	30554137570	2654661229	1.59E+09	4.51E+10	9276022	7310205
1001573983	2510513471	17442727580	525239686	9.6E+08	2.66E+10	7595500	7017176
3547881355	8466587109	5342759350	1071187443	2.01E+08	1.34E+10	7678852	7237962
4244053177	10766619420	1609828849	-641792978	2.01E+08	7.26E+09	7570986	7181883
5180821375	12368708430	-316956993	-1.333E+09	1.86E+08	4.41E+09	7602241	7225174
6748824947	14600111380	-2441226653	-1.696E+09	1.98E+08	1.77E+09	7763508	7375831
9072973656	15589320970	-5286835066	-2.083E+09	2.04E+08	-1.6E+09	7995745	7581611
11448356010	16076111720	-8181154877	-2.387E+09	2.05E+08	-5E+09	8115737	7678941
14863338630	17904460390	-1.1956E+10	-2.384E+09	1.97E+08	-8.9E+09	8304321	7806639
0	0	29394248380	3771829776	6.73E+08	4.45E+10	9156453	6874411
0	0	31981486300	3507338835	8.78E+08	4.8E+10	9831880	7486986
0	0.000988881	35747980190	2641799594	1.59E+09	5.07E+10	9423506	7297469
18086619.37	524065015	33774290820	156634828	1.23E+09	4.41E+10	8282467	7069792
579823728.1	3298166839	26247477800	-342740571	3.01E+08	3.4E+10	7744856	6973778
1571773140	5549699388	19333121840	-1.6E+09	2.01E+08	2.5E+10	7593677	6965591
3406105493	8620201536	13000064510	-2.434E+09	1.87E+08	1.74E+10	7593437	6997674
5531164173	11074010720	7288206169	-2.503E+09	2E+08	1.12E+10	7705696	7176346
9437241775	14819451400	-474654898	-2.447E+09	2.05E+08	3.06E+09	8025622	7523306
12869307720	17942193080	-6002102559	-2.096E+09	2.05E+08	-2.1E+09	8541920	7969961
11905838950	16210222530	-5455439498	-2.892E+09	1.97E+08	-2.7E+09	8354563	7830376
0	0	29394248380	3771829776	6.73E+08	4.45E+10	9156453	6874411
0	0	31981483730	3507338835	8.78E+08	4.8E+10	9831880	7486986
2.70E-17	2.75811E-06	36882478030	2756302610	1.73E+09	5.32E+10	10031736	7592137
2.68E-17	846167.703	38624051270	727344026	2.15E+09	5.21E+10	9583044	7219632
40209.217	18249570.17	37437271410	5857696.14	1.85E+09	4.86E+10	8818760	7102811
1624083.599	180133601.2	34600764420	-1.653E+09	1.58E+09	4.3E+10	8299699	7037538
83991789.47	937278232	30959729340	-3.004E+09	8.2E+08	3.65E+10	7958206	6984294
699327848	2977974101	23490119140	-3.677E+09	3.18E+08	2.69E+10	7679417	7033498
3001087249	6698987919	13161433990	-4.038E+09	2.05E+08	1.55E+10	7689181	7174649
8500910441	12814245630	1222890729	-3.498E+09	2.05E+08	3.75E+09	8224124	7707124
11460774660	15622254410	-3862332290	-2.753E+09	1.98E+08	-5.6E+08	8709586	8122395
0	0	29394248380	3771829776	6.73E+08	4.45E+10	9156453	6874411
0	0	31981483730	3507338835	8.78E+08	4.8E+10	9831880	7486986
3.70E-13	2.53074E-06	36878281680	2981847515	1.73E+09	5.35E+10	10072584	7630968
5632.408	465017.708	39609203090	1348884106	2.34E+09	5.46E+10	9992092	7434233

5609.29	3245045.894	40999569500	499018915	3.12E+09	5.54E+10	9848718	7330992
3645.922	8648049.931	41131823270	-1.111E+09	3.59E+09	5.4E+10	9771553	7261805
0.00026718	26231309.78	39869303650	-2.135E+09	3.21E+09	5.03E+10	9216565	7007165
0	64835342.57	34822086520	-2.499E+09	2.7E+09	4.33E+10	8517984	7017335
107766803.5	549812019.3	27142304760	-2.687E+09	1.55E+09	3.32E+10	7976796	7178367
746724340	1754321235	19869667600	-2.562E+09	9.51E+08	2.46E+10	7795871	7277055
1966141097	3320564857	14046561140	-2.968E+09	9.12E+08	1.78E+10	7658984	7236095
0	0	29394248380	3771829776	6.73E+08	4.45E+10	9156453	6874411
0	0	31981483730	3507338835	8.78E+08	4.8E+10	9831880	7486986
0	0	36892236180	3176769580	1.73E+09	5.4E+10	10193926	7747131
0	0	39680275450	2972975654	2.35E+09	5.77E+10	10514839	7926474
0	0	41860775850	1917707024	3.14E+09	5.98E+10	10616954	7938957
0	0	42668609650	-213854482	3.6E+09	5.87E+10	10498269	7832364
0	0	43038298390	-1.436E+09	3.96E+09	5.77E+10	10268842	7676166
0	0	40936403490	-1.719E+09	4.36E+09	5.51E+10	10159419	7752950
0	0	35332480670	-1.94E+09	4.74E+09	4.87E+10	10014053	7924046
0	0	30633360380	-2.015E+09	4.86E+09	4.32E+10	9825722	8048353
0	0	27049003560	-2.436E+09	4.67E+09	3.82E+10	9418887	7948266
0	0	30872683090	6894558733	5.48E+08	4.9E+10	8286062	6106337
0	0	33151923900	7161578136	7.33E+08	5.18E+10	8748512	6443245
0	0	36454559350	4476762383	1.5E+09	5.35E+10	9564997	6983375
67415333.33	1845829333	22911514290	721614238	8.68E+08	3.41E+10	9770745	7378650
363495000	5694960333	13019793930	-1.496E+09	8.56E+08	2.06E+10	9218903	7068786
1313429333	8602110000	6064363433	-2.285E+09	9.21E+08	1.19E+10	8196763	6467859
3293004000	9090268000	1875603819	-3.386E+09	9.53E+08	5.86E+09	7417859	5790486
7205286000	10568580000	-2972924572	-3.567E+09	9.47E+08	9374058	6556566	5295827
10720284670	12510168000	-6872422068	-3.736E+09	9.31E+08	-4.7E+09	6111998	4822445
11628235670	12918693330	-8159471231	-4.251E+09	9.09E+08	-7E+09	5636218	4384968
12361767000	13606992670	-8886574330	-4.162E+09	9.07E+08	-8E+09	5251328	4007440
0	0	30875871770	6894948483	5.48E+08	4.9E+10	8285953	6106337
0	0	33132878790	7161443786	7.33E+08	5.18E+10	8758093	6443245
0	14798666.67	36219184280	4437784919	1.49E+09	5.33E+10	9580786	6976084
61189333.33	1149261667	31750765980	2790836408	9.87E+08	4.63E+10	10277922	7599065
256457666.7	4564640667	26208463810	97148063.9	1.06E+09	3.72E+10	10349797	7781372
828157000	11005459670	18325215930	-1.995E+09	1.15E+09	2.65E+10	9923819	7693109
2459310333	16585477330	12620939560	-3.373E+09	1.1E+09	1.88E+10	9441261	7314837
5930734333	22888701000	5288097573	-3.278E+09	1.12E+09	1.12E+10	8757517	6910593
8666984333	24607289670	214677135.3	-4.26E+09	1.13E+09	4.39E+09	7835717	6465640
10180327670	23031107000	-2646276598	-3.849E+09	1.13E+09	1.17E+09	7268904	5940648
11366424670	20883863000	-4570578650	-3.787E+09	1.15E+09	-1.3E+09	6671173	5423402
0	0	30875885210	6894948483	5.48E+08	4.9E+10	8285953	6106337
0	0	33132839330	7161443786	7.33E+08	5.18E+10	8758093	6443245
0	6600000	36374401860	5311459130	1.49E+09	5.44E+10	9631906	7026713
20804666.67	238788000	37890790320	4140766338	1.33E+09	5.49E+10	10533281	7726294
118488333.3	1272102333	36303415400	1916251951	1.26E+09	5.03E+10	10912855	8069431
458403000	3753273333	33526900250	-914961693	1.23E+09	4.4E+10	10885182	8196909
1541345667	9559905667	26728912900	-2.426E+09	1.28E+09	3.51E+10	10501365	8068474

4020786000	18223894330	18553511950	-3.13E+09	1.32E+09	2.59E+10	10011508	7846793
6248308000	25325292670	11941196540	-3.967E+09	1.23E+09	1.79E+10	9009501	7539847
7699860667	28697324330	6617872360	-4.758E+09	1.25E+09	1.14E+10	8466669	7058645
9249130000	30033615330	3010926951	-4.429E+09	1.27E+09	7.51E+09	7935093	6488844
0	0	30875879500	6894948483	5.48E+08	4.9E+10	8285953	6106337
0	0	33132850030	7161443786	7.33E+08	5.18E+10	8758092	6443245
0	0	36614540740	5670387997	1.49E+09	5.5E+10	9657447	7049354
6537666.667	78829666.67	39797164350	4588490119	1.54E+09	5.77E+10	10608980	7766986
36586000	415873333.3	41313937900	3177632881	1.43E+09	5.75E+10	11182377	8241589
151033666.7	1329727667	42149946470	682209671	1.27E+09	5.53E+10	11372071	8506016
468629333.3	3384582667	40998072440	-1.956E+09	1.34E+09	5.1E+10	11265046	8555433
1350433333	7474463333	36823849840	-2.631E+09	1.39E+09	4.58E+10	10868119	8450018
3052155333	14496617670	29625244140	-3.801E+09	1.41E+09	3.69E+10	9965779	8241015
4914063000	23273308670	20027979270	-4.559E+09	1.44E+09	2.62E+10	9361891	7885944
6361483333	31789710330	13915123670	-4.8E+09	1.37E+09	1.95E+10	8776604	7415498
0	0	30875824860	6894948483	5.48E+08	4.9E+10	8285953	6106337
0	0	33132832630	7161443786	7.33E+08	5.18E+10	8758093	6443245
0	0	36732975960	5659252105	1.49E+09	5.52E+10	9686537	7077714
0	0	41457853860	4667361668	1.81E+09	6.02E+10	10669539	7791600
0	0	45673434400	3871394132	2.29E+09	6.45E+10	11386542	8365284
0	0	50303836400	2281902526	2.58E+09	6.79E+10	11755891	8783467
0	86969666.67	54122052590	541496776	2.68E+09	6.97E+10	11898688	9022266
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2156000	1910692667	58649808720	-2.676E+09	1.5E+09	6.9E+10	11383193	9105311
24522666.67	4893977000	60196809370	-3.978E+09	1.56E+09	6.9E+10	11345697	8962341
100455666.7	7979198333	59696348950	-4.27E+09	1.63E+09	6.76E+10	11193341	8696078
0	0	30874045870	6894948483	5.48E+08	4.9E+10	8285950	6106337
0	0	33133194490	7161443786	7.33E+08	5.18E+10	8758082	6443245
0	0	37148024860	5114400392	1.51E+09	5.53E+10	9742624	7099679
0	0	42507302020	4220248626	1.97E+09	6.13E+10	10959872	7806830
0	0	47740715230	3865736274	2.43E+09	6.74E+10	11930028	8402180
0	0	53614470790	3037158405	2.89E+09	7.36E+10	12689418	8869951
0	0	59467087800	1935181211	3.38E+09	7.93E+10	13157974	9210878
0	0	65089404510	907574490	4.02E+09	8.48E+10	13459986	9423901
0	0	74067977700	65651579.8	4.69E+09	9.39E+10	13872232	9550357
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0	0	86165767690	-481563299	6.06E+09	1.07E+11	15094255	9618958
0	0	29596083800	4777850700	5.32E+08	4.63E+10	8950428	6313233
0	0	32480035400	6918580200	7.48E+08	5.24E+10	9664651	6885117
0	0	39493257100	7144479100	8.55E+08	6.14E+10	10993034	7984993
0	0	42677379000	5614802400	4.55E+08	6.38E+10	11970619	8989430
316645900	3089636300	29327171000	3225675200	3.33E+08	4.44E+10	9835121	7707130
2422931400	10527017400	21171744300	1759150800	99106100	3.35E+10	10374127	8562131
5095818300	16985182600	14495744600	2258294700	88768800	2.76E+10	10827643	9054788
7895301900	18000532100	8290314000	1204390700	84219300	2.02E+10	10938404	9356065
9787142700	18404618500	3568871200	356313300	81037400	1.47E+10	11080860	9644234
11407319100	18565512200	-396494300	-316920700	78039900	1.01E+10	11240519	9908333

12639289900	18560994000	-3347244900	-514697800	76554200	6.98E+09	11425757	10157225
0	0	29596083800	4777850700	5.32E+08	4.63E+10	8950428	6313233
0	0	32480035400	6918580200	7.48E+08	5.24E+10	9664651	6885117
0	0	39493257100	7144479100	1.08E+09	6.16E+10	10993034	7984993
0	0	44837617900	5751522800	1.03E+09	6.7E+10	12268201	9087305
0	554381800	39322943600	3703282200	6.48E+08	5.62E+10	10814857	8372249
254794900	4720187600	33453629700	3108234400	3.19E+08	4.9E+10	11430567	9183179
2866992500	12478443700	22896697100	2573671100	4.17E+08	3.78E+10	11578524	9526728
5957084500	17682157700	17228383900	2485481400	3.76E+08	3.23E+10	12033261	10037675
7305074700	19369549700	14328994100	1629933700	3.73E+08	2.88E+10	12426462	10500535
8821674400	20567955200	10742908600	657119900	1.1E+08	2.41E+10	12670620	10843636
10637467800	21130234200	6260073100	141763200	3.09E+08	1.92E+10	12737918	11042824
0	0	29596083800	4777850700	5.32E+08	4.63E+10	8950428	6313233
0	0	32480035400	6918580200	7.48E+08	5.24E+10	9664651	6885117
0	0	39493257100	7144479100	1.15E+09	6.17E+10	10993034	7984993
0	0	45038009600	5767258100	1.24E+09	6.75E+10	12305752	9099834
0	2850000	43900313000	4174156800	1.18E+09	6.29E+10	11580485	8848924
0	404552900	43170493200	3717618900	1.08E+09	6.15E+10	12303306	9671239
0	756389300	43682796800	4365639000	1.19E+09	6.37E+10	13165761	10468250
0	2982843900	39840726500	3685950700	9.28E+08	5.91E+10	13586151	11007236
377485000	7454211100	35043513100	2510682300	8.14E+08	5.33E+10	14017275	11519289
1686761200	12738987400	31325724700	2386466200	7.07E+08	4.98E+10	14603967	12089257
3454191200	16334610000	28617158800	2631043300	8.04E+08	4.79E+10	15122359	12599470
		29596083800	4777850700	5.32E+08	4.63E+10	8950428	6313233
		32637746100	6923006200	7.48E+08	5.26E+10	9696905	6890739
		41088257200	7414449600	1.16E+09	6.39E+10	11340142	8111850
		49158915300	5841971200	1.3E+09	7.24E+10	12869535	9271320
		55239447900	4637857400	1.44E+09	7.89E+10	14145163	10273478
		60206473500	3794889500	1.53E+09	8.45E+10	15316645	11235351
		64222705700	3739589600	1.58E+09	8.98E+10	16404087	12158780
		68480647900	3312017800	1.64E+09	9.5E+10	17491047	13071485
		72728153200	2843305300	1.71E+09	1E+11	18562328	13976418
		77572247000	2564936400	1.8E+09	1.06E+11	19618343	14852001
		82558844400	2656121100	1.91E+09	1.13E+11	20656195	15696995
0	1813315031	32646976520	3128786018	9.41E+08	4.6E+10	10629113	8004550
63447843.84	2566112191	38638997820	1409787543	1.13E+09	5.3E+10	11076643	8546870
1558426104	9776825449	24755425680	-933615185	2.48E+08	3.69E+10	10898958	9323329
3650670817	15773641440	16421459180	-97235951	2.45E+08	2.91E+10	11688874	10187774
6237648239	20061980980	9512715803	2368667435	2.6E+08	2.24E+10	12420963	10952498
9532677330	23252746750	1645026937	5021001216	2.74E+08	1.48E+10	13252447	11806898
12663301320	24568908850	-6162634035	6039512586	2.86E+08	7.04E+09	13988388	12559384
15684998540	24992356640	-1.354E+10	2917535882	2.97E+08	-4.1E+08	14395245	12962068
18705289100	26883717840	-2.0063E+10	971396780	3.11E+08	-7.2E+09	14382531	12918876
23713467510	31790895160	-2.7729E+10	184772631	3.33E+08	-1.5E+10	14545515	13017220
0	1813315031	32646976470	3128786018	9.41E+08	4.6E+10	10629113	8004552

63447844.36	2566112191	38638996080	1409800650	1.13E+09	5.3E+10	11076644	8546871
513836331.3	5407643142	36025535260	-1.004E+09	4.87E+08	4.91E+10	11202337	9371571
1343569877	9527415052	29180102130	-1.081E+09	3.51E+08	4.27E+10	11865218	10168825
2690606140	13947034730	20523568250	-583822575	2.63E+08	3.4E+10	12493815	10904899
5005424528	17825592420	12739333940	2059411062	2.7E+08	2.65E+10	13178919	11643347
8040044438	20762954210	5007923513	5239011074	2.78E+08	1.88E+10	13906228	12412662
11206577020	23018415630	-3082679635	5856200199	2.87E+08	1.07E+10	14614628	13153508
14205855820	24003471600	-1.0817E+10	3685234328	2.95E+08	2.88E+09	15071887	13620484
17146466380	25722261680	-1.7439E+10	1477333711	3.05E+08	-4E+09	15110869	13635039

0	1813315031	32646976430	3128786018	9.41E+08	4.6E+10	10629113	8004552
63447844.36	2566112191	38638995160	1409800650	1.13E+09	5.3E+10	11076644	8546871
319340722.8	4402635891	39924554130	-473467893	8.31E+08	5.38E+10	11499234	9458487
728805740.2	6754661587	37337668670	-771584391	5.85E+08	5.17E+10	12143385	10250332
1387229395	9971512924	30044859920	-1.01E+09	3.91E+08	4.43E+10	12723870	10988598
2660596055	13571520230	21167666660	312778505	2.72E+08	3.54E+10	13271694	11641311
4684329802	16665978370	13312564610	2402792751	2.76E+08	2.75E+10	13894998	12330426
5416087424	17101215690	11488394390	-556876893	2.79E+08	2.62E+10	14634682	13072416
5883447851	17499026790	9928128253	-145536010	2.79E+08	2.49E+10	15205340	13657785
7025113686	18194774700	6446823513	1247195656	2.78E+08	2.16E+10	15759038	14237441

0	1813315031	32646976430	3128786018	9.41E+08	4.6E+10	10629113	8004552
63447844.36	2566112191	38638995000	1409800650	1.13E+09	5.3E+10	11076644	8546871
177727733.4	3772848009	45160886470	959892051	2.65E+09	6.29E+10	13014814	9627683
299785137.6	4858995410	47483618380	1511267258	2.9E+09	6.64E+10	13953231	10531886
401609317.9	5746969603	47525229300	1529462049	2.76E+09	6.67E+10	14547569	11419394
548962041.3	6634781779	46201039890	1411483434	2.24E+09	6.5E+10	14982018	12156491
663957157.8	7221827363	43627608290	963407382	1.58E+09	6.17E+10	15251950	12839312
827545261.7	7914499770	37408773430	-603009879	9.51E+08	5.46E+10	15396403	13422229
1110128254	8904439154	30242028090	-1.677E+09	5.21E+08	4.68E+10	15676960	13883899
1686669882	10428045430	22476442520	-1.907E+09	3.5E+08	3.87E+10	16009754	14343027

0	0	29385721490	2501447876	7.57E+08	4.42E+10	9925504	7349251
0	0	32646988710	3128786018	9.41E+08	4.91E+10	10629113	8004552
0	0	40417488040	1218539006	1.75E+09	5.73E+10	11701522	8611060
0	0	47694335230	1375235017	2.77E+09	6.77E+10	13174145	9657130
0	0	51591229000	2255699817	3.1E+09	7.44E+10	14429187	10596362
0	0	53078258600	2586178806	3.33E+09	7.73E+10	15602554	11531024
0	0	53691959560	3262017104	3.46E+09	7.94E+10	16613990	12330270
0	0	52929922310	2968286161	3.54E+09	7.91E+10	17606023	13121766
0	0	49420809640	1752113352	3.56E+09	7.45E+10	18493649	13882043
0	0	46575217220	957501541	3.54E+09	7.1E+10	19312971	14520689
0	0	44329322090	455399639	3.51E+09	6.97E+10	20173531	15168227
0	0	29550000000	5733000000	6.73E+08	4.76E+10	9813947	7167947
0	0	32200000000	4170000000	8.7E+08	5E+10	10277903	7844903

168000	702000	38370000000	1321000000	1.41E+09	5.45E+10	10769411	8602411
590000000	694000000	36130000000	1643000000	9.09E+08	4.92E+10	9806412	8081412
6600000000	7170000000	17730000000	4408000000	1.87E+08	3.19E+10	10855107	9145107

16100000000	16800000000	-3893000000	5147000000	1.49E+08	1.08E+10	12740634	10870634
19200000000	19900000000	-1.416E+10	1317000000	1.53E+08	-3.8E+09	12543652	10623652
20500000000	21000000000	-1.711E+10	859900000	1.77E+08	-7.6E+09	12002279	9982279
21600000000	21700000000	-1.863E+10	704400000	1.78E+08	-9.5E+09	12187886	9997886
22100000000	22200000000	-1.945E+10	-102300000	1.72E+08	-1.2E+10	11728601	9438601
22500000000	22500000000	-2.011E+10	-1.201E+09	1.83E+08	-1.4E+10	11234967	8914967
0	0	29550000000	5682942500	6.73E+08	4.76E+10	9806726	7160726
0	0	32200000000	4135005000	8.7E+08	5E+10	10300588	7867588
168000	702000	38370000000	1182252300	1.41E+09	5.45E+10	10758180	8591180
134000000	369000000	41610000000	1548648300	9.09E+08	5.6E+10	10458312	8638312
1700000000	4010000000	35770000000	2248976700	1.87E+08	4.86E+10	9976049	8334049
7430000000	12000000000	21150000000	3832273800	1.49E+08	3.51E+10	10483699	8973699
14000000000	18900000000	3784000000	3699276800	1.53E+08	1.72E+10	11884582	10424582
17200000000	21300000000	-6230000000	2240670400	1.77E+08	5.36E+09	12075051	10555051
19400000000	21600000000	-1.242E+10	1072327500	1.78E+08	-2.8E+09	11786224	10096224
21000000000	21900000000	-1.7E+10	507444100	1.72E+08	-8.6E+09	11720263	9720263
22100000000	22600000000	-1.918E+10	202014800	1.83E+08	-1.1E+10	11547910	9297910
0	0	29550000000	5682942500	6.73E+08	4.76E+10	9806726	7160726
0	0	32200000000	4135005000	8.7E+08	5E+10	10300588	7867588
168000	702000	38370000000	1170850200	1.45E+09	5.46E+10	10758180	8591180
43300000	279000000	43100000000	1375965000	1.12E+09	5.87E+10	10718811	8808811
477000000	3050000000	42640000000	887087500	5.64E+08	5.58E+10	10421960	8614960
2020000000	10700000000	36800000000	620238200	1.49E+08	4.8E+10	9272135	7616135
5780000000	17300000000	26140000000	2314157200	1.53E+08	3.85E+10	9587742	8162742
10200000000	20800000000	13000000000	2511429100	1.77E+08	2.52E+10	10485312	9075312
14900000000	21900000000	612200000	2136193000	1.79E+08	1.18E+10	10943469	9383469
19400000000	22300000000	-9651000000	1115723200	1.73E+08	-1.7E+08	11441236	9681236
21100000000	22500000000	-1.386E+10	260597600	1.84E+08	-6.1E+09	10800801	8920801
0	0	29550000000	5682942500	6.73E+08	4.76E+10	9806726	7160726
0	0	32200000000	4135005000	8.7E+08	5E+10	10300588	7867588
168000	702000	38370000000	1163470000	1.53E+09	5.46E+10	10758180	8591180
35400000	256000000	43570000000	1369095600	1.8E+09	5.99E+10	10786199	8836199
380000000	2620000000	45130000000	869293100	1.45E+09	5.99E+10	10679969	8778969
1600000000	10100000000	42910000000	316773000	9.49E+08	5.53E+10	9834250	7960250
4070000000	18500000000	36200000000	967689900	5.23E+08	4.8E+10	9523839	7889839
6500000000	22700000000	28510000000	973003200	2.88E+08	3.97E+10	9744845	8262845
8380000000	23300000000	22990000000	663049400	1.94E+08	3.32E+10	9723995	8256995
10100000000	22800000000	16910000000	260311100	1.87E+08	2.59E+10	9464186	7939186
10800000000	22800000000	15840000000	16737200	2.06E+08	2.35E+10	8828340	7265340
0	0	29550000000	5682942500	6.73E+08	4.76E+10	9806726	7160726
0	0	32200000000	4135005000	8.7E+08	5E+10	10300588	7867588
168000	702000	38370000000	1181359500	1.57E+09	5.47E+10	10758180	8591180
5960000	132000000	46480000000	1355990100	2.25E+09	6.42E+10	11101755	8981755
55300000	1570000000	53380000000	1135741600	2.38E+09	7.12E+10	11339988	9199988
219000000	7460000000	58060000000	111771300	2.4E+09	7.41E+10	10537639	8379639
513000000	17000000000	58930000000	6160700	2.33E+09	7.38E+10	10118517	8046517
910000000	22800000000	55220000000	81195200	2.46E+09	6.92E+10	9713114	7736114

1420000000	24000000000	50330000000	210237300	1.63E+09	6.23E+10	9330693	7403693
2100000000	23800000000	44090000000	941111100	8.34E+08	5.39E+10	8630530	6760530
2810000000	23800000000	40980000000	-20562300	8.47E+08	4.96E+10	7872276	6072276
0	0	29550000000	5732640500	6.73E+08	4.76E+10	9813947	7167947
0	0	32200000000	4171124600	8.78E+08	5E+10	10277903	7844903
0	0	39550000000	5062389300	1.73E+09	6.04E+10	11994362	9364362
0	0	51160000000	5566452000	2.5E+09	7.53E+10	12889186	10149186
0	0	65840000000	4025617000	2.89E+09	9.14E+10	13578425	10648425
0	0	82130000000	2306466100	3.44E+09	1.08E+11	13317114	10177114
0	0	1.012E+11	150416400	4.1E+09	1.26E+11	13529877	10409877
0	0	1.177E+11	-238674100	4.83E+09	1.43E+11	13484531	10344531
0	0	1.296E+11	-147852200	5.11E+09	1.55E+11	13483656	10163656
0	0	1.309E+11	-495368200	4.96E+09	1.54E+11	13225089	9775089
0	0	1.276E+11	-1.53E+09	4.7E+09	1.49E+11	12723682	9243682

Ammonia emissions	NOx emissions	Organic carbon emissions	Sulfur emissions	VOC emissions	Freight transport energy	Passenger transport energy	Final energy	Final energy (electricity)	Final energy (gases)
57252530	1.33E+08	34307961	1.17E+08	1.56E+08	23586.44	51535.72	94659.94	14858.6	14632.81
63370296	1.33E+08	36628929	1.2E+08	1.61E+08	24706.31	52415	102022.6	17600.12	15088.05
65452771	1.12E+08	29281071	77310097	1.19E+08	31615.94	68243.55	96283.46	20475.07	16039.61
64920241	62378103	19670691	33131302	73392567	33417.13	68646.8	76348.26	19542.79	15204.95
65249185	46320523	19580160	18772619	76607723	41927.66	88176.82	80272.37	23141.35	15747.12
64527895	36245009	15823020	15778996	80854920	48817.4	106733.8	89059.29	30641.08	15049.48
63767207	33596395	15123670	14515230	83718705	54692.62	120896	95645.38	37951.31	13186.74
63494497	32540362	14640320	13013372	76982286	59254.58	131040.6	100209.5	43505.45	10885.3
63336046	30991118	13917360	10974212	60431515	62292.56	137685.2	101952.5	46522.01	8630.86
62943553	29108899	13006560	8707670	44897979	64143.62	140115.9	101123.5	47118.15	7354.334
62757524	28354803	12274840	6544224	33902567	65302.4	138994.6	98795.75	45633.04	6714.7
57252530	1.33E+08	34307961	1.17E+08	1.56E+08	23586.44	51535.72	94659.94	14858.6	14632.81
63370296	1.33E+08	36628929	1.2E+08	1.61E+08	24706.3	52415	102022.5	17600.12	15088.04
65458926	1.24E+08	29974100	92217560	1.29E+08	32350.74	69550.39	107002.5	22776.54	18417.54
64550449	91244644	20448059	51781521	93529834	39975.9	87041.42	110755	28327.47	23071.78
64046095	78481323	18729111	34236938	96492814	47462.24	104368.6	115322.2	33304.81	27958.41
63919444	63132701	17063910	24878540	1.03E+08	53708.36	118513.3	118909.4	37998.11	29122.11
63100295	56529266	16008030	20117041	1.06E+08	58802.96	129721.4	123071.6	43596.95	27758.91
62970935	49586587	16021749	16614031	94495153	62676.46	137779.2	122295.9	47413.73	24164.74
63262780	40977950	15224790	12700078	71209128	65360.46	142016.4	118157.4	49492.98	18862.07
63821339	36089663	14762580	9756788	52171577	67435.57	143146.7	115136.3	49645.6	14644.86
62568349	32438861	12643560	7383750	38393875	67079.69	140685.4	115780.5	53329.99	13755.99
57252530	1.33E+08	34307961	1.17E+08	1.56E+08	23586.44	51535.72	94659.94	14858.6	14632.81
63370296	1.33E+08	36628929	1.2E+08	1.61E+08	24706.3	52415	102022.5	17600.12	15088.04
65520294	1.26E+08	30174271	95622780	1.31E+08	32481.98	69769.05	109755.1	23377.29	18959.58
64974828	98959306	21692101	61189461	1.01E+08	40423.25	87962.43	119694.2	30677.19	25216.47
64492434	90786752	20089540	49187481	1.09E+08	48334.61	106415.7	131117.5	37969.53	32381.58
64058055	74827147	17549589	37063622	1.18E+08	54748.36	121437.7	140196.6	44335.17	35513.36
63056418	66913640	16557261	29915880	1.22E+08	59637.85	132831.4	145207.5	50130.07	35455.67
62496617	56615356	15924560	22333780	1.08E+08	62963.59	140145.9	141900.9	53482.63	31213.8
62231384	45110950	15013320	15266986	79972764	64871.04	143574.4	132101.5	54597.9	23939.9
62950149	37872851	14343660	10582134	56920318	66684.02	143852.4	123895.5	53973.02	16058.9
63693268	34950701	14584560	7790372	43016641	67014.65	141101.3	120611.1	54556.77	12337.23
57252530	1.33E+08	34307961	1.17E+08	1.56E+08	23586.44	51535.72	94659.94	14858.6	14632.81
63370296	1.33E+08	36628929	1.2E+08	1.61E+08	24706.3	52415	102022.5	17600.12	15088.04
65725726	1.27E+08	30750540	95745659	1.32E+08	32489.09	69774.67	109744.3	23408.55	18852.5
65550721	1.01E+08	23389009	63506741	1.04E+08	40499.54	88084.35	121362.8	31120.41	25716.46

65022605	97138591	21508751	58428501	1.15E+08	48581.52	106896.7	137205.5	39774.45	34343.5
64397584	84188545	18172899	53150921	1.26E+08	55153.21	122268.5	150270.2	47613.12	38281.28
63110841	76333484	16355860	45285702	1.3E+08	60158.14	133891.7	157331.4	54619.82	39255.53
62486892	65074061	15682000	34398121	1.16E+08	63684.91	141450.1	156565.2	59165.46	36450.33
62148963	50963826	14902050	23519899	88201717	65473.13	144820	149285.3	61707.27	31419.8
61770513	39635110	13914040	14746346	63454505	66243.93	144604	138859.1	62168.6	24951.27
60931843	32617609	12258870	9688266	45158742	66217.85	141534.4	130142.7	61799.75	19391.44
57252530	1.33E+08	34307961	1.17E+08	1.56E+08	23586.44	51535.72	94659.94	14858.6	14632.81
63370296	1.33E+08	36628929	1.2E+08	1.61E+08	24706.3	52415	102022.5	17600.12	15088.04
65915706	1.27E+08	31225559	95878540	1.33E+08	32493.46	69777.97	109794	23418.94	18869.04
66816046	1.04E+08	27416611	64427422	1.1E+08	40513.88	88103.35	121699	31192.39	25602.83
66041586	99984813	24607969	60487122	1.2E+08	48650.55	107025.5	138926.4	40269.2	34794
64791848	86621157	19053640	56424320	1.29E+08	55227.02	122425.2	152111.1	48279.37	39286.62
63130712	80452327	16092541	53727020	1.32E+08	60305.7	134154.8	161444.9	56139.49	40852.12
62523007	72084926	15416780	48621479	1.21E+08	63931.41	141883.8	165289.8	62528.64	39416.23
62164095	58645301	14677250	38789501	93792450	65965.62	145499.3	162777	67373.86	36026.22
61667248	46631548	13403940	28824760	67539198	66963.79	145521.6	156012.6	69612.22	31649.91
60712022	37471568	12041380	19804228	47907949	66733.94	142455.2	146752.7	69404.42	27420.28
53311985	1.18E+08	32788420	1.08E+08	1.92E+08			89745.07	15054.18	13385.57
55391244	1.12E+08	32779763	1E+08	1.88E+08			100480.9	17704.18	14593.62
49017490	1.04E+08	30234324	76406009	1.78E+08			121880.1	22761.13	15362.23
47190186	79802280	28237975	39257572	1.67E+08			117732.9	27124.47	15032.23
44647999	62598875	25958219	27407723	1.53E+08			116718.7	36957.53	19607.24
40612011	53912909	23561260	24649652	1.38E+08			121697.9	49233.65	27382.52
36762506	50982523	21056046	23015668	1.28E+08			131503.2	59522.83	30903.08
33839254	48509417	18509965	20838205	1.18E+08			140739.8	68928.94	29720.3
31744079	46160086	15928535	18938202	1.06E+08			150369.6	77530.06	28482.52
30264763	43669903	14011262	17201823	96324705			160087.9	85765.07	28383.91
29157855	41740367	13209558	16087878	92070142			171726.2	94928.13	30385.86
53311879	1.18E+08	32788517	1.08E+08	1.92E+08			89733.41	15054.18	13385.57
55391080	1.12E+08	32779506	1E+08	1.88E+08			100512.3	17704.18	14593.35
47446506	1.03E+08	30253298	76106893	1.78E+08			121818.4	22815.3	15148.07
48613481	90562273	28456995	54884506	1.72E+08			132648.4	28230.02	14999.73
48340300	76704356	26418585	35557614	1.62E+08			140093.2	34778.08	18632.24
46932245	65223686	24170570	26997506	1.47E+08			145913.5	44497.26	25524.19
44995728	60881793	21723496	25752987	1.35E+08			155615.1	55736.43	32853.08
41757230	58818169	19280390	25423773	1.22E+08			165121.2	68336.72	42996.42
38142461	55976980	16797840	24776132	1.12E+08			176510.7	79495.9	46069.76
35227297	52472877	14834049	22279189	1.02E+08			187570.7	90554.52	46498.09
32943961	48956111	13964566	19593698	96034253			201186.5	102640.4	48790.04
53311879	1.18E+08	32788517	1.08E+08	1.92E+08			89733.41	15054.18	13385.57
55391081	1.12E+08	32779500	1E+08	1.88E+08			100512.3	17704.18	14593.35
48538528	1.04E+08	30205917	76394847	1.78E+08			121829	22773.07	15547.23
51478546	98758745	28502199	65058482	1.74E+08			138625.4	28114.47	15868.35
52411875	86249560	26552324	49420869	1.67E+08			152290.4	34061.42	18700.57
51215310	77160040	24424562	39086969	1.56E+08			162528.2	41879.48	23675.85
49656583	68443039	22073453	32546421	1.41E+08			169619.9	52357.26	31235.86

47475218	63654822	19611427	27386266	1.29E+08	182018.2	61355.05	44325.87
45042846	59940277	17073827	25101105	1.15E+08	194610.4	72820.06	57093.1
42717643	57513421	15244832	25077999	1.07E+08	206192.1	86860.9	61043.94
39714351	54961487	14515687	24495394	1.04E+08	221311.6	100799.5	62219.22
53311879	1.18E+08	32788517	1.08E+08	1.92E+08	89733.41	15054.18	13385.57
55391078	1.12E+08	32779500	1E+08	1.88E+08	100512.3	17704.18	14593.35
48907312	1.04E+08	30183053	76779945	1.78E+08	122049	22733.63	15488.62
52915679	1.01E+08	28506840	72012877	1.75E+08	141517.3	28243.08	15528.07
55230967	90414941	26605900	59622242	1.68E+08	158485.7	34032.25	18074.74
55558188	83246750	24472385	48491201	1.59E+08	171562.4	41637.26	21857.8
54612257	76873134	22232003	42770105	1.46E+08	180952.9	51827.82	25827.24
52417313	71389706	19908906	38527958	1.34E+08	192411	61407.27	34360.03
49918622	66600884	17426649	34058628	1.21E+08	206954.1	69653.67	50415.04
47652420	61113035	15458670	28036548	1.09E+08	221569.1	79420.62	67280.61
45776741	58002888	14609433	24866807	1.03E+08	237571.9	92735.91	78309.23
53311879	1.18E+08	32788527	1.08E+08	1.92E+08	89733.41	15054.18	13385.57
55391081	1.12E+08	32779500	1E+08	1.88E+08	100512.3	17704.18	14593.35
49241564	1.04E+08	30197707	76941086	1.78E+08	122102	22733.63	15355.85
53855443	1.02E+08	28753617	77071207	1.75E+08	143212.9	28446.97	15426.68
57446165	94028460	26741032	68892340	1.69E+08	161666.2	34363.08	18080.29
60132049	88039094	24657581	59987498	1.61E+08	176647.1	41805.03	21503.35
61737246	83144982	22420164	55433520	1.49E+08	189505.2	52336.71	23460.57
60338393	77391872	20041463	49114445	1.38E+08	201934.3	63371.44	25856.41
58630678	74591867	17671837	45855792	1.31E+08	219801.6	71919.78	27739.74
57401985	71245470	15869921	42844127	1.26E+08	239946.9	79891.45	27687.24
55790124	67281343	15095103	38963058	1.23E+08	261107.7	89140.9	29776.97
53311876	1.18E+08	32788520	1.08E+08	1.92E+08	89732.57	15054.18	13385.57
55391055	1.12E+08	32779484	1E+08	1.88E+08	100512.3	17704.18	14593.35
50094262	1.04E+08	30278136	77969162	1.78E+08	122313.4	22744.74	15444.73
54419642	1.03E+08	28686193	79198786	1.75E+08	144246.5	28622.52	15585.57
57800607	95724742	26795279	72288668	1.69E+08	163101.8	34383.36	18290.01
60676602	90067498	24789173	65157221	1.61E+08	178869.9	41843.37	21045.02
62749454	85687352	22617675	61169703	1.51E+08	192858.2	52368.93	22503.07
63778857	80530130	20294772	56309629	1.4E+08	207202.9	64114.77	23571.96
63859411	78658440	17954287	52964512	1.33E+08	226423.8	72892.28	24515.02
64738704	76236743	16175726	48530784	1.29E+08	247655.5	81091.45	24571.69
65407187	72884597	15470049	43897887	1.27E+08	270511.9	91264.24	24693.91
52609600	1.23E+08	38066200	1.19E+08	2.1E+08	92822.52	15178.76	14949.96
53595900	1.16E+08	36648800	99761100	2.06E+08	100320.3	17068.46	16076.65
55837600	1.24E+08	36374300	1.03E+08	2.12E+08	122808.3	21168.18	20660.18
58200800	1.22E+08	35672600	97845100	2.11E+08	139833.6	25029.41	24878.27
58128100	84629400	31637800	55125400	1.94E+08	128419.6	27222.02	21236.24
58341600	75016500	30100700	43142000	1.91E+08	133181.1	32009.75	21316.68
58546400	69024900	28433500	35947700	1.85E+08	137015.1	37609.64	20945.74
57819500	62548700	26883100	30470400	1.76E+08	137568.9	44921.87	17997.38
57460300	57834500	25676200	26245000	1.68E+08	139328.4	52383.65	15229.76
57356100	54710500	24636400	22875100	1.6E+08	143110.5	60499.02	12845.45

57507800	53184300	23739700	20256000	1.53E+08						149298.1	68868.86	11055.18
52609600	1.23E+08	38066200	1.19E+08	2.1E+08						92822.52	15178.76	14949.96
53595900	1.16E+08	36648800	99761100	2.06E+08						100320.3	17068.46	16076.65
55837600	1.24E+08	36374300	1.03E+08	2.12E+08						122808.3	21168.18	20660.18
58248700	1.25E+08	35727000	1E+08	2.12E+08						143372.9	25601.91	25617.02
59109100	1.03E+08	32763100	72692800	2.01E+08						143206.4	27329.66	26629.88
59547900	91637600	30944900	58983900	1.97E+08						147128.4	29761.13	28493.69
59223100	78480900	28645700	43693800	1.89E+08						146801.5	34978.08	27399.88
59524000	74503800	27185500	37680300	1.83E+08						151240.1	38595.81	28200.44
59645300	71212000	25812900	33973600	1.76E+08						155017.3	43532.09	27915.55
59688200	67368900	24554500	29944000	1.69E+08						158460	49708.87	26199.24
59570600	63252300	23419300	25745100	1.61E+08						161540.5	57455.63	22983.3
52609600	1.23E+08	38066200	1.19E+08	2.1E+08						92822.52	15178.76	14949.96
53595900	1.16E+08	36648800	99761100	2.06E+08						100320.3	17068.46	16076.65
55837600	1.24E+08	36374300	1.03E+08	2.12E+08						122808.3	21168.18	20660.18
58252900	1.25E+08	35732800	1.01E+08	2.12E+08						143649.5	25683.58	25637.99
59506700	1.12E+08	33483000	82974200	2.05E+08						149753.6	28275.3	28278.52
60232900	1.06E+08	31824000	74715900	2.02E+08						156329.5	30941.14	31356.97
60712800	1.03E+08	30120300	70425800	1.97E+08						164031.6	33647.83	35891.67
60723500	96056400	28190600	61024800	1.9E+08						168505	35874.72	38691.56
61023800	89474000	26447600	52701200	1.84E+08						172716.4	38963.86	40542.45
61625200	85773000	24998000	46939700	1.78E+08						179838.7	43278.06	42581.53
62145300	83214300	23602600	42348100	1.72E+08						187754.9	48715.62	44083.67
52609600	1.23E+08	38066200	1.19E+08	2.1E+08						92822.52	15178.76	14949.96
53601600	1.17E+08	36655400	1E+08	2.06E+08						100497.1	17064.6	16088.96
55882500	1.29E+08	36445300	1.07E+08	2.12E+08						124576.8	21593.43	20729.27
58365700	1.33E+08	35836900	1.07E+08	2.14E+08						146030	26786.08	25797.47
60405900	1.35E+08	35204500	1.07E+08	2.12E+08						161166.6	31701.41	29765.47
61905000	1.36E+08	33860900	1.06E+08	2.12E+08						172053.1	37178.36	33548.42
62862300	1.33E+08	32100900	1.02E+08	2.08E+08						180299.3	41435.34	37965.09
63575200	1.3E+08	30451900	98786500	2.03E+08						188529.4	45668.59	41383.45
64319100	1.26E+08	28853900	95054400	1.98E+08						196848.6	50095.6	44652.34
65200300	1.23E+08	27370500	89455300	1.93E+08						206498.9	54668.4	47816.12
66126900	1.19E+08	25897700	82541000	1.88E+08						216383.2	59620.3	51081.6

52338447	1.09E+08	36065237	1E+08	1.54E+08	27877.41	63560.13	109403.3	18254.26	17649.46			
61761490	1.11E+08	31858344	96043410	1.7E+08	39066.31	77057.51	131621.5	25795.87	19939.02			
68042818	82431063	32820865	55153636	1.59E+08	47765.41	87313.47	138656.3	36620.52	19956.54			
73237931	67842202	33672877	38644663	1.57E+08	56267.85	95279.86	148863.3	47299.79	20136.4			
77084917	59648453	34710961	30907309	1.58E+08	61922.93	99909.97	154096.1	57885.04	18786.45			
79766916	51747872	32744791	26126558	1.51E+08	64986.83	101862.5	156283.4	67181.41	16914.93			
81349299	44730093	29869102	23140201	1.41E+08	66671.15	101693.2	156989.9	75007.42	14876.13			
80324017	34085085	22632578	20362663	1.2E+08	66968.51	100026.2	156418.1	81090.15	12855.88			
76576647	25777406	18172266	18908764	1.04E+08	66885.15	97310.17	155947	86297.02	10970.26			
74157414	19729080	14907335	18729518	94551638	67462.36	93697.56	158428.9	92748.88	9322.643			

52338447	1.09E+08	36065238	1E+08	1.54E+08	27877.41	63547.16	109403.3	18254.26	17649.46			
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61761490	1.11E+08	31858335	96043408	1.7E+08	39031.56	77082.48	131621.5	25795.87	19939.02
68518057	98721750	31852399	75661714	1.67E+08	49498.26	88249.5	145305.9	33867.23	22190.13
73786023	82929168	32075639	57008450	1.63E+08	58859.77	96825.54	156947.6	42658.74	23368.08
78076765	67333385	31355405	40527236	1.58E+08	65456.52	102210.6	162676.8	51591.64	22963.95
80836913	58193482	29820286	32174753	1.53E+08	69532.36	105148.2	164745.6	59947.97	21688.17
82943288	51205066	29906055	27248226	1.48E+08	72196.93	105990.6	164880.8	68327.58	19500.49
84209784	42535393	28338574	23427843	1.35E+08	72702.85	104808.7	163116.5	75287.2	17055.27
83300739	33584273	22712575	20888418	1.18E+08	72077.69	102329.8	160787.2	80691.22	14725.75
79757822	25706578	18095963	19373512	1.03E+08	71075.36	98815.94	159297.2	85531.99	12585.33

52338447	1.09E+08	36065238	1E+08	1.54E+08	27877.41	63547.16	109403.3	18254.26	17649.46
61761490	1.11E+08	31858335	96043408	1.7E+08	39031.56	77082.48	131621.5	25795.87	19939.02
68674078	1.04E+08	31412794	83522583	1.7E+08	50385.22	88700.69	148826.6	33075.88	23097.53
74228884	93730475	31397276	70266339	1.68E+08	60266.49	97548.41	161760.2	40771.17	24761.04
78753749	77965238	30308028	53429290	1.62E+08	67545.8	103315.7	168421.5	48267.86	25092.57
81508865	64708808	28272231	39815118	1.56E+08	72320.14	106789.4	171091	55348.44	24486.98
83768680	55675915	27485530	31560889	1.5E+08	75638.88	108247.3	171130.5	62958.68	22824.02
86251542	47002587	19467821	28459254	1.33E+08	79792.86	109631.6	173905.4	65682.64	23715.11
87771081	42475451	17910126	26719114	1.27E+08	83114.09	109935.1	174765.3	68163.62	23971.76
88838694	37930150	18473316	24626494	1.22E+08	84636.43	108844.6	173422.1	71577.39	23068.13

52338447	1.09E+08	36065238	1E+08	1.54E+08	27877.41	63547.16	109403.3	18254.26	17649.46
61761490	1.11E+08	31858335	96043408	1.7E+08	39031.56	77082.48	131621.5	25795.87	19939.02
68967840	1.1E+08	30892323	95051686	1.75E+08	51860.54	89365.2	154709.5	32885.9	23903.43
74676335	1.06E+08	30191319	89050302	1.76E+08	62697.15	98619.77	170470.1	39314.15	26239.07
79766105	97735576	29073850	80247739	1.74E+08	71370.58	104969.3	180331.2	44610.21	27622.8
83509746	90131870	26596503	72113049	1.71E+08	78104.83	109392.2	186468.1	48658.58	28510.69
86712501	81759932	24382476	62772873	1.65E+08	83766.57	112150.8	189528.6	52402.04	28901.38
89086445	67996945	21536499	49556399	1.53E+08	87630.64	113322.5	189441	55651.32	28818.69
89812289	57016247	19369327	39435531	1.41E+08	90254.04	113312.5	187402.9	59112.25	28415.3
90698042	47827677	18416347	32109073	1.31E+08	91603.71	112371.7	184553.6	62943.39	27795.91
46905961	1.12E+08	31285759	1.15E+08	1.55E+08	24644.52	53575.07	99737.11	15448.36	16015.22
52338447	1.09E+08	36065238	1E+08	1.54E+08	27877.41	63547.16	109403.3	18254.26	17649.46
61922658	1.13E+08	32187336	1E+08	1.73E+08	39505.89	77438.25	133627.9	26010.95	20478.81
69229225	1.13E+08	31316550	97979371	1.78E+08	52215.92	89510.29	155595.3	33166.02	23795.49
75042748	1.09E+08	30316383	93226039	1.79E+08	63284.48	98846.35	171863.1	39550.5	26168.08
80202546	1.02E+08	28603453	85534953	1.77E+08	72257.67	105288.1	182339.9	44761.42	27627.45
84079084	95453395	26590607	78806001	1.76E+08	79409.05	109857.4	189465.7	48456.42	28703.58
87793320	88151967	24242515	70946165	1.72E+08	85700.58	112834.6	193890.8	51643.71	29390.53
89826772	75915997	21255378	59432918	1.59E+08	90530.3	114350.8	195636.4	53872.95	29785.16
91577125	67313124	18919223	51448342	1.51E+08	94593.49	114865.3	196032.1	55663.28	30198.43
93354460	59735820	16786883	44291864	1.44E+08	98049.37	114752.1	196325.4	57118.9	30833.91
39337300	1.17E+08	29106100	1.14E+08	1.55E+08	85050	38050	91861.18	14861.12	14252.79
42243600	1.11E+08	27760700	94597200	1.52E+08	93100	41740	99000.08	17491.68	15766.68
49795600	1.13E+08	26096300	74469400	1.52E+08	134600	65450	125222.3	24369.46	20363.91
56015700	92643000	23067100	48171800	1.39E+08	167900	89580	137139	28944.47	14322.23
65023500	66677200	19562300	29076200	1.19E+08	162400	94110	132805.7	40138.92	10188.9

73552900	46048400	17471300	18508800	1.01E+08	162800	108100	142166.8	64638.94	7825.006
81449100	40572700	16579500	14767800	90694700	130700	133200	150277.9	89388.96	5988.894
86182200	38863100	15974300	13913200	86309100	120200	156600	170805.7	109611.2	5830.56
86967400	37946700	15615300	13672700	82635300	124100	187500	191166.8	126305.7	6244.449
87669100	35777500	15155300	13045900	78748400	125000	208500	209805.7	143500.1	6350.005
86862800	33145500	14853400	11879900	74809200	127400	237400	224694.6	156777.9	6202.783
39271500	1.17E+08	28982600	1.14E+08	1.55E+08	85050	38050	91861.18	14861.12	14252.79
42481200	1.11E+08	28399200	94702800	1.53E+08	93100	41740	99000.08	17491.68	15766.68
49648400	1.14E+08	26350000	74507300	1.52E+08	134600	65450	125222.3	24369.46	20363.91
55902200	99143900	23292100	50752200	1.4E+08	179600	94300	149694.6	32583.36	18972.24
60683500	78595200	20285200	34264100	1.25E+08	199000	108600	160722.4	42750.03	17494.46
67873100	55079600	18291700	22473200	1.12E+08	218800	126800	172777.9	59277.83	17522.24
77841500	48620200	17207900	16864100	98930600	223200	142000	175611.3	78972.29	15538.9
82780000	42591600	16573500	13399700	88636600	208000	159400	184833.5	100555.6	15194.46
85816600	37860300	16015900	11557200	83560300	183500	188600	198750.2	118527.9	13430.57
88170700	36005900	15668700	11943300	79408800	169500	203500	214250.2	137250.1	9677.786
87410300	34524900	15287800	12248000	75404200	163900	237000	229778	151194.6	9063.896
39271500	1.17E+08	28982600	1.14E+08	1.55E+08	85050	38050	91861.18	14861.12	14252.79
42481200	1.11E+08	28399200	94702800	1.53E+08	93100	41740	99000.08	17491.68	15766.68
49648400	1.14E+08	26350000	74514300	1.52E+08	134600	65450	125222.3	24369.46	20363.91
55669000	1.01E+08	23468400	53476100	1.4E+08	178500	94340	151166.8	34083.36	20619.46
59920100	83410200	20536300	36908700	1.27E+08	202900	110900	168666.8	44750.04	22227.8
63119000	59973200	18854100	25382000	1.15E+08	235200	133200	186944.6	59916.71	23619.46
69928100	54135000	17920400	19880600	1.05E+08	256700	151200	194694.6	75694.51	24008.35
75658900	47191200	17113500	15276500	92649600	250100	165700	199000.2	92305.63	26516.69
80005200	41027500	16437600	12135900	84649700	236000	193900	209333.5	112694.5	23600.02
83506300	36461100	16009700	10915600	79998600	218000	209400	221722.4	130833.4	17141.68
84517400	33119600	15641500	10102700	75947300	200800	236500	232861.3	144666.8	13152.79
39271500	1.17E+08	28982600	1.14E+08	1.55E+08	85050	38050	91861.18	14861.12	14252.79
42481200	1.11E+08	28399200	94702800	1.53E+08	93100	41740	99000.08	17491.68	15766.68
49648400	1.14E+08	26350000	74514300	1.52E+08	134600	65450	125222.3	24369.46	20363.91
55740300	1.02E+08	23546900	55425900	1.41E+08	179100	94590	152083.5	34305.58	20625.02
59923500	86381900	20734500	39816900	1.27E+08	205400	112200	173055.7	45055.59	23613.91
63321100	65216100	19062100	28100500	1.17E+08	242800	136800	196444.6	59388.94	27319.47
68969200	60091300	18290400	23111200	1.09E+08	276000	158000	210666.8	73055.61	29916.69
72888500	53993800	17588600	18558000	98530900	289500	173000	218750.2	87027.85	36194.47
74318900	48690000	17063000	15249400	89284200	311700	203900	233166.9	103305.6	39527.81
74962700	42480700	16506800	13220100	82409100	313900	223700	243861.3	118333.4	36861.14
73470300	37798900	16104100	11467400	77177000	330200	254700	258028	127722.3	40861.14
39271500	1.17E+08	28982600	1.14E+08	1.55E+08	85050	38050	91861.18	14861.12	14252.79
42481200	1.11E+08	28389200	94700800	1.53E+08	93100	41740	99000.08	17491.68	15766.68
49648400	1.14E+08	26350000	74508300	1.52E+08	134600	65450	125222.3	24369.46	20363.91
56245600	1.06E+08	23754000	60934900	1.41E+08	182600	95850	156166.8	35361.14	21933.35
59740000	94948700	21055700	50130800	1.29E+08	215500	116000	184666.8	47555.59	27236.13
62091800	75617100	19450000	36751700	1.2E+08	258600	143500	213222.4	60944.49	32444.47
65603700	72420800	18790000	29266700	1.15E+08	300400	167700	233722.4	70527.83	39000.03
67951500	65562600	18206100	23190700	1.06E+08	327000	183200	248028	80083.4	50361.15

68859500	58446200	17754700	18754200	97114100	364000	212600	261333.5	92972.3	56166.71
68540500	50456300	17305700	15771500	88150500	375000	231700	268472.4	108111.2	56638.93
66432700	43611100	16815600	13043000	81580700	387600	261500	279722.4	117777.9	63388.94
39337300	1.17E+08	29106100	1.14E+08	1.55E+08	85050	38050	91861.18	14861.12	14252.79
42243600	1.11E+08	27750700	94595200	1.52E+08	93100	41740	99000.08	17491.68	15766.68
49875500	1.17E+08	28145500	77239400	1.55E+08	135200	65570	125139	24908.35	18850.02
56405400	1.12E+08	25552200	65961300	1.44E+08	185800	96860	159805.7	35638.92	23175.02
60553900	1.05E+08	22302700	59927800	1.31E+08	225700	119500	197805.7	49583.37	34777.81
62747700	88065700	20332500	48566900	1.22E+08	274700	149700	232694.6	64861.16	42611.15
66896100	89181400	19431200	41758000	1.18E+08	328100	178700	261222.4	76138.95	50777.82
70696500	87537900	18737400	35218700	1.12E+08	368100	199300	285000.2	85750.07	61250.05
71354400	83521000	18304000	29339400	1.06E+08	425800	232200	307778	95694.52	66694.5
71355700	74865000	17733200	24667800	97176700	460700	250700	316944.7	105972.3	68166.72
69138500	63535500	17142000	18952800	87767600	485100	280100	324166.9	114416.8	75388.95

Final energy (heat)	Final energy (hydrogen)	Final energy (industry)	Final energy (liquids)	Final energy (residential/commercial)	Final energy (solids)	Final energy (traditional biomass)	Final energy (transport)	Radiative forcing	Radiative forcing (aerosols)
3680.478	1.91E-06	28803.27	42149.23	32357.69	19338.83	10553.69	25079.37	1.870916	-1.11517
4083.709	0.10653	33812.83	42081.13	34022.74	23169.45	11266.13	24831.47	2.139458	-1.05053
3242.755	5.545885	32795.05	38729.98	30646.3	17790.49	5952.919	26012.24	2.582151	-0.88032
2030.806	2920.313	29913.39	22333.99	25876.74	14315.43	2981.283	17312.28	2.843904	-0.58559
1568.672	11819.6	31243.19	16198.48	27875.26	11797.13	2594.487	18288.08	2.791113	-0.48819
1401.934	15181.73	33728.69	14899.71	31751.84	11885.36	2290.657	19828.87	2.634877	-0.43835
1141.998	14935.96	35460.36	14791.12	35792.93	13638.25	1829.056	20318.33	2.469284	-0.42607
869.194	15211.33	35100.03	15143.24	39596	14594.96	1358.427	21380.41	2.336205	-0.41347
659.2483	16528.12	33468.11	14807.99	41591.39	14804.27	1036.26	22776.23	2.207992	-0.39178
481.8698	18754.32	30800.33	13741.91	42016.77	13672.91	735.7428	24254.54	2.068866	-0.36447
347.792	21858.62	27815.36	12478.16	41740.91	11763.46	446.8262	25411.49	1.905195	-0.34318
3680.478	1.91E-06	28803.27	42149.23	32357.69	19338.83	10553.69	25079.37	1.870916	-1.11517
4083.709	0.10653	33812.8	42081.13	34022.74	23169.43	11266.13	24831.47	2.135342	-1.05491
3732.17	4.049789	37248.45	42367.76	33462.53	19704.46	6417.03	28436.91	2.551068	-0.97582
3080.014	259.9785	39031.26	38356.62	35255.77	17659.14	3881.47	29422.52	2.931325	-0.7469
2463.71	879.2871	40590.61	33608.79	38006.7	17107.16	3474.336	31073.05	3.092123	-0.63699
2016.901	1229.747	40659.84	32251.64	40527.23	16290.89	2877.05	31288.22	3.124641	-0.55117
1529.622	2453.096	40877.56	31404.78	44107.35	16328.2	2267.683	31515.69	3.089988	-0.5054
1112.317	5111.401	38593.48	28946.26	46223.52	15547.47	1702.658	30962.47	3.024207	-0.47206
788.4087	12046.53	35338.81	22805.51	46370.19	14161.89	1261.484	30443.64	2.916334	-0.43055
573.5718	18890.22	31727.11	19011.63	46759.32	12370.47	877.8849	30899.8	2.769267	-0.39889
419.0526	18759.15	29105.64	19098.8	49642.17	10417.45	549.7346	30677.25	2.637267	-0.36004
3680.478	1.91E-06	28803.27	42149.23	32357.69	19338.83	10553.69	25079.37	1.870916	-1.11517
4083.709	0.10653	33812.8	42081.13	34022.74	23169.43	11266.13	24831.47	2.1344	-1.05592
3840.475	4.39467	38421.81	43353.23	34113.16	20220.1	6524.672	29090.5	2.568914	-0.99923
3373.128	260.7912	42617.23	40979.18	38009.59	19187.46	4207.931	31325.72	3.006489	-0.82262
2937.68	835.4843	45951.07	37768.45	43234.41	19224.79	3976.664	34612.11	3.270402	-0.75556
2494.568	943.6385	47432.62	37843.87	47632.21	19066.05	3418.961	36455.45	3.47776	-0.65081
1886.552	1505.033	47529.84	37339.03	51815.57	18891.19	2730.274	37286.11	3.602119	-0.58833
1328.265	2560.994	44643.73	35176.21	53267.49	18138.98	2036.958	36146.5	3.676591	-0.51882
904.3152	5693.841	39366.2	30215.88	52415.58	16749.67	1462.251	33515.64	3.660825	-0.45007
621.8869	13022.6	34508.28	24593.97	51103.74	15625.09	967.5258	32313.42	3.54306	-0.40562
450.7676	17667.53	30829.44	21880.4	51465.45	13718.4	563.2296	32400.11	3.383062	-0.3867
3680.478	1.91E-06	28803.27	42149.23	32357.69	19338.83	10553.69	25079.37	1.870916	-1.11517
4083.709	0.10653	33812.8	42081.13	34022.74	23169.43	11266.13	24831.47	2.13433	-1.05603
3840.792	4.395865	38428.39	43405.54	34080.27	20232.48	6525.575	29101.83	2.571433	-1.00275
3423.795	254.4227	43188.42	41593.97	38478.53	19253.75	4279.289	31705.58	3.021749	-0.84861

3095.419	840.0762	48082.9	39503.18	45199.08	19648.91	4186.184	35929.75	3.320321	-0.83175
2694.688	948.1271	51315.62	40261.71	51020.33	20471.27	3688.761	38640.33	3.597944	-0.77368
2055.109	1388.148	51391.76	39980.12	56265.3	20032.67	2989.461	39963.01	3.858525	-0.70532
1481.636	2210.044	48793.73	38178.37	59033.44	19079.31	2290.96	39437.81	4.079861	-0.61379
1039.058	3266.039	44392.28	34012.86	59442.94	17840.32	1721.051	37021.64	4.209114	-0.51556
705.6778	4444.017	39374.03	29997.59	57958.49	16591.9	1168.176	34088.28	4.268145	-0.42964
472.2423	6064.555	34688.28	27103.7	56366.41	15310.97	669.982	32327.47	4.270901	-0.3703
3680.478	1.91E-06	28803.27	42149.23	32357.69	19338.83	10553.69	25079.37	1.870916	-1.11517
4083.709	0.10653	33812.8	42081.13	34022.74	23169.43	11266.13	24831.47	2.134266	-1.05613
3841.55	4.399876	38440.23	43429.95	34094.98	20230.12	6526.647	29118.3	2.576915	-1.00585
3435.272	253.9158	43551.59	41600.03	38557.72	19614.6	4274.045	31766.05	3.067757	-0.87126
3143.208	846.7329	48861.82	39838.46	45716.08	20034.82	4230.42	36300.61	3.450918	-0.85968
2734.426	952.8746	51461.07	40798.21	51685.44	20059.62	3744.603	39070.92	3.798741	-0.80384
2112.892	1396.559	52752.52	40840.25	57722.52	20103.6	3068.519	40884.84	4.089258	-0.76863
1566.54	2291.281	51652.88	39740.05	62286.05	19747.01	2419.758	41255.51	4.366412	-0.72084
1128.275	3519.517	48529.74	35751.97	64888.58	18977.21	1892.147	39685.37	4.622711	-0.63436
786.5912	4903.179	44154.2	31610.84	65223.75	17449.83	1324.84	37484.06	4.833992	-0.54025
526.6532	6298.936	38979.34	28206.77	63725.27	14895.64	778.1809	35607.81	5.009074	-0.45371
3043.891	0	32468.36	39848.37	33208.36	18331.68	8144.729	24068.07	1.870916	-1.11517
3206.391	0	37503.36	41997.81	36444.47	22360.02	8473.062	26533.35	2.137667	-1.05306
3720.836	0	46014.76	53367.82	42347.81	24216.96	7867.229	33517.53	2.623028	-0.93934
5946.949	530.8338	42955.31	44118.09	41591.98	19800.85	7269.728	33185.58	2.997782	-0.70567
7112.783	1905.835	42669.48	28662.52	42681.15	14741.12	6240.838	31368.08	3.001046	-0.59917
6928.061	2638.613	45286.43	13303.07	45406.7	13131.95	5005.004	31004.75	2.847006	-0.55885
5710.282	4226.67	47681.15	11886.4	49307.26	9185.563	3635.836	34514.47	2.672744	-0.53856
5375.838	4564.448	49105.87	17363.63	54338.1	3928.892	2247.502	37295.86	2.487768	-0.51761
5936.671	4615.837	50878.93	20488.63	59796.99	2000.279	750.5562	39693.64	2.281985	-0.49729
6578.339	4625.559	52285.88	22081.68	66052.28	1240.834	0	41749.76	2.072509	-0.4793
7141.117	4238.892	54022.54	22305.02	73214.78	1246.945	0	44488.65	1.882197	-0.46397
3043.891	0	32456.97	39836.7	33208.36	18331.68	8144.729	24068.07	1.870916	-1.11517
3206.391	0	37509.75	42004.48	36469.2	22384.74	8473.062	26533.35	2.137809	-1.05292
3926.114	0	46119.2	53105.6	42290.31	24309.19	7867.229	33408.92	2.619799	-0.9414
5747.227	283.3336	48844.21	53207.82	46242.54	24669.19	7269.728	37561.7	3.004945	-0.80373
6845.839	1106.39	52017.26	50521.43	48697.54	19648.35	6240.838	39378.36	3.224943	-0.66835
8201.951	2470.002	55711.71	38828.36	52268.1	16048.35	5005.004	37933.36	3.249548	-0.59742
9402.785	3871.948	58009.21	29034.75	56959.77	13179.73	3635.836	40646.14	3.182839	-0.58372
8692.229	5047.782	59193.94	19546.4	61205.88	8130.284	2247.502	44721.7	3.081103	-0.57851
8903.896	5529.171	61501.99	16609.46	66329.78	6919.172	750.5562	48678.93	2.946145	-0.56444
8445.562	5469.171	62744.77	17797.51	72505.06	5556.393	0	52320.88	2.792915	-0.53943
8641.118	5435.282	64187	19117.24	80343.68	3090.836	0	56655.88	2.643176	-0.51119
3043.891	0	32456.97	39836.7	33208.36	18331.68	8144.729	24068.07	1.870916	-1.11517
3206.391	0	37509.75	42004.2	36469.2	22384.74	8473.062	26533.35	2.137674	-1.05305
3810.003	0	46055.59	53220.6	42279.76	24009.19	7867.229	33493.64	2.622219	-0.94735
5186.671	51.11115	51257.82	57441.99	47166.15	26573.91	7269.728	40201.42	3.02461	-0.87498
5782.227	353.6114	55947.27	58341.99	51116.15	26378.08	6240.838	45226.98	3.357604	-0.76014
6044.727	887.2229	60754.49	53971.43	55000.04	25233.63	5005.004	46773.65	3.533795	-0.68464
6444.727	2113.891	64994.22	43236.7	60364.77	21992.24	3635.836	44260.87	3.634248	-0.63276

8380.562	3533.614	67520.61	36400.03	66479.22	14908.35	2247.502	48018.37	3.673553	-0.59919
11433.34	4348.337	68437.83	27570.3	73263.67	7507.228	750.5562	52908.93	3.650251	-0.58042
12230.01	5557.782	69158.67	20659.18	79346.73	5596.949	0	57686.44	3.577758	-0.57019
12276.12	6303.338	71494.78	19265.85	86647.01	5862.782	0	63169.77	3.486103	-0.5531
3043.891	0	32456.97	39836.7	33208.36	18331.68	8144.729	24068.07	1.870916	-1.11517
3206.391	0	37509.75	42004.48	36469.2	22384.74	8473.062	26533.35	2.137552	-1.05317
3736.947	0	46134.2	53193.65	42396.98	24448.63	7867.229	33517.8	2.62302	-0.95176
5076.115	0	52752.82	57698.38	47921.15	29683.63	7269.728	40843.09	3.014606	-0.91873
4895.282	244.7224	58650.32	60561.72	52618.65	32125.86	6240.838	47216.7	3.394818	-0.8275
4881.671	447.7781	63993.66	59915.05	56920.05	31701.97	5005.004	50648.37	3.674516	-0.75301
5580.56	1561.39	69155.33	52582.54	62653.11	30912.8	3635.836	49144.48	3.89118	-0.70503
7414.45	2810.558	73558.95	43301.98	69062	29527.25	2247.502	49790.04	4.070099	-0.67132
9259.73	3662.781	75732.84	35413.08	76123.67	24261.13	750.5562	55097.82	4.202828	-0.63922
11259.73	5034.726	77219.51	27337.8	83875.9	16522.79	0	60473.66	4.272958	-0.59836
13450.29	6520.839	78401.73	22323.07	92553.96	9147.23	0	66616.16	4.280675	-0.57352
3043.891	0	32456.97	39836.7	33208.36	18331.68	8144.729	24068.07	1.870916	-1.11517
3206.391	0	37509.75	42004.2	36469.2	22384.74	8473.062	26533.35	2.137499	-1.05323
3697.781	0	46174.76	53297.26	42409.76	24570.58	7867.229	33517.8	2.623053	-0.95449
4490.281	0	53876.99	58480.88	48140.04	31065.3	7269.728	41195.87	3.010648	-0.95274
3947.781	148.3335	60285.33	61940.61	53316.99	34794.19	6240.838	48063.93	3.444984	-0.88809
3593.614	582.7782	66177	63063.94	58055.32	35313.08	5005.004	52414.76	3.843814	-0.82909
3746.67	915.2785	72733.11	58188.66	64732.55	37918.64	3635.836	52039.76	4.217579	-0.79107
5415.56	1620.001	77865.9	53309.76	71945.61	38260.59	2247.502	52122.82	4.579262	-0.74638
7643.339	2883.891	82848.4	57240.32	79387.01	37506.42	750.5562	57566.43	4.892227	-0.72265
10873.62	6001.116	87958.68	63363.94	88103.68	36701.97	0	63884.5	5.188424	-0.70114
12078.34	8383.618	92503.41	68263.39	97827.58	37581.42	0	70776.72	5.488135	-0.67303
3043.891	0	32455.86	39835.87	33208.36	18331.68	8144.729	24068.07	1.870916	-1.11517
3206.391	0	37509.75	42004.48	36469.2	22384.74	8473.062	26533.35	2.137271	-1.05348
3483.336	0	46305.04	52895.88	42489.48	25297.8	7867.229	33518.92	2.621972	-0.95996
3946.392	0	54548.38	58570.88	48318.65	32270.86	7269.728	41379.48	3.016565	-0.96481
3411.392	149.1668	61096.72	62748.94	53531.15	35879.47	6240.838	48473.93	3.469712	-0.91134
3177.78	585.2782	67383.11	64354.22	58375.6	37064.47	5005.004	53110.88	3.922371	-0.85972
3257.78	869.7229	74352.84	60428.1	65267	40495.03	3635.836	53238.38	4.394603	-0.82717
3838.336	1430.834	80741.18	55811.43	73488.95	44187.26	2247.502	52972.82	4.897461	-0.79114
5380.56	3290.558	86680.35	61531.16	81081.18	43771.7	750.5562	58662.55	5.421348	-0.77162
8679.174	6835.839	92354.52	69743.11	89548.13	41078.09	0	65752.83	5.982997	-0.74727
10266.95	8400.562	97734.8	76783.12	99807.3	42841.42	0	72969.78	6.560877	-0.71699
3071.919		35279.75	39557.2	34468	19847.21		23074.77	1.870916	-1.11517
3502.058		37264.2	42463.84	37604.42	20892.16		25451.69	2.133461	-1.05832
4376.67		44819.59	51740.46	45876.18	24281.96		32112.58	2.62038	-1.05672
5292.115		52027.96	56237.21	51622.24	27554.27		36183.42	3.144272	-1.00245
5787.477		47676.9	52596.88	49893.68	21246.74		30849.05	3.583005	-0.74743
6520.45		50103.54	50931.32	51445.18	22077.68		31632.41	3.654403	-0.65892
7079.006		52752.68	47797.73	52360.24	23263.82		31902.11	3.67028	-0.60667
7741.562		54299.74	42476.2	52339.99	24177.13		30929.19	3.671116	-0.5689
8327.146		56369.85	37699.97	52369.74	25481.44		30588.75	3.640354	-0.53959
8861.313		59243.16	33655.92	52726.71	27076.91		31140.66	3.588572	-0.51607

9404.146	63241.13	30782.3	53450.93	29041.16	32606	3.522411	-0.49848
3071.919	35279.75	39557.2	34468	19847.21	23074.77	1.870916	-1.11517
3502.058	37264.2	42463.84	37604.42	20892.16	25451.69	2.133461	-1.05832
4376.67	44819.59	51740.46	45876.18	24281.96	32112.58	2.624063	-1.05764
5293.976	52669.21	58051.44	52714.79	27905.22	37988.89	3.16509	-1.0252
5705.143	52872.13	58703.63	53846.4	24210.96	36487.92	3.63922	-0.85827
5874.727	55172.6	57557.41	54964.88	24809.41	36990.86	3.869095	-0.75849
6515.7	56265.82	52542.49	54840.57	24836.55	35695.06	4.0363	-0.65716
6789.117	59316.69	50846.01	55505.88	26291.83	36417.61	4.128543	-0.61656
7250.645	62322.55	47987.46	55979.71	27842.22	36715.08	4.204479	-0.59388
7804.923	65280.89	44866.65	56206.88	29444.94	36972.22	4.263437	-0.56796
8470.479	68181.47	41118.31	56142.32	31154.44	37216.75	4.293275	-0.54016
3071.919	35279.75	39557.2	34468	19847.21	23074.77	1.870916	-1.11517
3502.058	37264.2	42463.84	37604.42	20892.16	25451.69	2.133461	-1.05832
4376.67	44819.59	51740.46	45876.18	24281.96	32112.58	2.625554	-1.05774
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5784.449	55437.77	60203.6	55556.49	26378.58	38759.34	3.664934	-0.92088
5914.894	58832.13	59767.71	57419.21	27440.33	40078.12	3.988574	-0.86623
5889.394	63240.86	57883.96	59214.38	29644.5	41576.37	4.312689	-0.8375
5928.283	66394.55	56225.02	59911.71	30718.11	42198.76	4.660433	-0.77719
6123.977	69704.22	54062.35	60374.6	31987.97	42637.59	4.944131	-0.72588
6374.866	74349.25	52527.18	61409.24	34023.11	44080.23	5.183833	-0.6919
6837.45	79354.06	50493.98	62467.49	36556.58	45933.37	5.410145	-0.66614
3071.919	35279.75	39557.2	34468	19847.21	23074.77	1.870916	-1.11517
3501.225	37274.11	42567.4	37609.67	20955.74	25613.35	2.132032	-1.05977
4389.92	45014.45	52586.63	46178.43	24661.1	33383.89	2.617478	-1.08775
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6498.477	64624.02	60672.72	61308.66	32673.03	46120.4	4.29286	-1.08097
6517.227	69276.81	58158.32	63412.75	34538.14	47609.7	4.839877	-1.06926
6520.005	74028.95	56349.66	65124.94	36746.61	49375.51	5.395268	-1.0574
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6580.144	90537.04	51306.18	69938.06	45510.54	55908.07	7.165433	-0.98283

2701.973	0	48508.09	43841.42	33096.45	26956.14	8491.139	27346.69	2.135616	-1.05572
2767.583	92.31838	58485.16	51971.99	39927.69	31054.68	9495.258	32646.98	2.615401	-0.99488
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1221.922	622.6288	60423.4	58521.22	46658.46	21061.3	11745.65	41262.52	3.204259	-0.6486
735.3802	1041.755	61847.12	57587.43	48432.98	18060.01	12244.63	43342.77	3.255243	-0.60057
376.1912	1477.216	62852.19	54567.92	49104.11	15765.7	12604.08	43911.11	3.26705	-0.56657
155.1244	2087.28	64776.63	50560.52	49191.95	14303.45	12733.68	42665.37	3.236566	-0.53545
48.99802	2790.234	68041.28	46192.82	48694.64	13440.04	12654.5	39386.16	3.143147	-0.46992
11.98928	3572.18	73327.01	42562.55	47555.4	12533.02	12119.17	34825.29	2.944663	-0.42729
2.156813	4400.868	82492.57	40893.3	45843.79	11061.05	10825.39	29901.99	2.664341	-0.40271

2701.973	0	48508.09	43841.42	33096.45	26956.14	8491.139	27346.69	2.135616	-1.05572
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2767.583	92.3178	58485.16	51971.99	39927.69	31054.68	9495.258	32646.98	2.609302	-1.00115
2198.401	285.6392	62143.71	58755.19	44521.3	28009.3	10680.94	38088.17	3.012552	-0.89439
1740.612	557.2728	65452.2	62911.4	48064.05	25711.47	11247.29	42912.55	3.316284	-0.76188
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757.8078	1247.838	66471.2	62023.48	50126.98	19080.38	11947.39	47729.97	3.599732	-0.5868
395.8454	1686.4	66658.96	58879.94	49717.71	16090.52	12026.73	48143.85	3.647063	-0.56231
169.3263	2178.072	67626.46	54459.86	48700.56	13966.79	11970.65	46484.75	3.64861	-0.53032
57.74609	2751.873	70197.89	50024.51	47258.48	12536.15	11594.09	43079.21	3.582218	-0.47848
14.94661	3334.38	75073.65	46435.93	45651.98	11394.6	10926.78	38365.65	3.425418	-0.43667
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2767.583	92.3178	58485.16	51971.99	39927.69	31054.68	9495.258	32646.98	2.607601	-1.00299
2437.231	281.8351	64497.9	59891.61	45227.71	30042.5	10458.99	38548.67	3.015267	-0.93426
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1568.714	853.0959	70221.43	66840.17	50693.81	25799.07	11327.55	47032.85	3.640454	-0.72238
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653.7831	1499.085	69409.39	64323.06	50433.41	18871.89	11614.4	50926.99	3.935974	-0.57313
520.9109	1733.124	71116.33	64543.15	49567.31	17710.45	11158.75	52914.26	4.01949	-0.50505
392.7899	1919.49	72571.94	64344.19	47682.28	15973.46	10208.16	54252.31	4.06636	-0.48972
249.0487	2094.911	73405.53	62771.02	45509.21	13661.63	9396.814	54289.19	4.110232	-0.48657
2701.973	0	48508.09	43841.42	33096.45	26956.14	8491.139	27346.69	2.135616	-1.05572
2767.583	92.3178	58485.16	51971.99	39927.69	31054.68	9495.258	32646.98	2.606071	-1.00486
2783.683	282.7678	68334.51	61297.8	46611.49	33555.92	10061.38	39212.41	3.063226	-0.97452
2605.444	535.3603	74443.54	67706.25	50727.74	34069.81	10427.04	44781.75	3.522897	-0.92912
2316.082	837.0964	78250.32	71721.44	52785.83	33223.58	10582.59	48822.87	3.928056	-0.87019
1980.414	1056.849	80225.1	74828.05	53265.35	31433.53	10501.48	52562.09	4.287897	-0.82257
1601.953	1280.032	80912.62	76490.95	52655.87	28852.27	10245.25	55601.05	4.625374	-0.76462
1229.145	1479.183	80502.67	76535.56	51036.7	25727.1	9820.371	57595.26	4.934061	-0.66715
880.6666	1669.476	79656.21	75166.01	48734.43	22159.17	9176.197	58753.82	5.152049	-0.59421
587.1139	1828.339	78828.88	72778.54	46295.81	18620.29	8539.322	59210.43	5.293856	-0.54642
2650.637	0	43727.62	41495.3	30742.02	16189.01	7938.579	24985.54	1.870916	-1.11517
2701.973	0	48508.09	43841.42	33096.45	18465	8491.139	27346.69	2.134948	-1.05654
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2808.293	285.5336	68866.35	61720.32	46819.63	23838.41	9981.251	39358.56	3.182663	-0.99157
2656.13	541.7463	75306.91	68424.8	51026.87	24208.44	10313.45	45012.7	3.756655	-0.95201
2405.745	850.5726	79598.42	72762.38	53112.1	23592.62	10339.7	49157.57	4.286486	-0.89687
2129.215	1076.905	82279.09	76402.04	53700.7	22515.07	10182.43	53070.78	4.776581	-0.85874
1823.589	1305.609	83939.99	78857.25	53206.55	21041.22	9828.849	56385.71	5.25394	-0.81058
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1287.616	1714.148	85501	80844.71	49552.22	17873.03	8450.834	60721.14	6.083381	-0.67222
1061.125	1853.532	86370.08	81342.41	47393.56	16360.62	7754.914	62344.05	6.425488	-0.62586
3061.114	96.36119		35972.25		23627.8	9063.896	24141.69	1.870916	-1.11517
2925.002	108.889		37388.92		25311.13	9291.674	25991.69	2.138911	-1.05226
2966.669	132.5557		55222.27		22161.13	6388.894	37888.92	2.679534	-0.92699
2215.002	455.2781		77694.51		13511.12	2902.78	49527.82	3.096875	-0.74187
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4136.114	9500.008	51694.49	4383.337	0	42583.37	3.161707	-0.47103
7194.45	11261.12	34444.47	2001.113	0	38277.81	2.91258	-0.44464
9922.23	12841.68	31555.58	1021.112	0	40722.25	2.629362	-0.43927
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3061.114	96.36119	35972.25	23627.8	9063.896	24141.69	1.870916	-1.11517
2925.002	108.889	37388.92	25311.13	9291.674	25991.69	2.138941	-1.05221
2966.669	132.5557	55222.27	22161.13	6388.894	37888.92	2.678085	-0.92715
2908.336	213.9724	80888.95	14163.9	2902.78	52416.71	3.142186	-0.76715
2958.336	960.2785	88027.85	8544.451	808.334	57305.6	3.435167	-0.62639
2886.113	2571.669	85055.62	5450.004	0	60555.6	3.558382	-0.50837
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7475.006	6377.783	53305.6	1959.724	0	52194.49	3.382893	-0.43928
10416.68	9902.786	44888.92	1574.168	0	53388.93	3.176578	-0.4211
12936.12	13519.46	39388.92	1493.89	0	54083.38	2.919882	-0.42299
14225.01	16419.46	37527.81	1365.834	0	58555.6	2.656269	-0.42371
3061.114	96.36119	35972.25	23627.8	9063.896	24141.69	1.870916	-1.11517
2925.002	108.889	37388.92	25311.13	9291.674	25991.69	2.138945	-1.05221
2966.669	132.5557	55222.27	22161.13	6388.894	37888.92	2.678056	-0.92803
3369.447	202.8613	76916.73	15963.9	2902.78	52388.93	3.172607	-0.78732
3483.336	651.6672	86583.4	10952.79	808.334	58777.82	3.558691	-0.65113
3400.003	1696.946	90861.18	7444.45	0	65583.39	3.778043	-0.53605
3386.114	3086.114	84000.07	4497.226	0	66972.28	3.875289	-0.4993
5105.56	4702.782	67611.17	2728.058	0	61805.61	3.903814	-0.46194
7866.673	7102.783	55944.49	2101.668	0	60861.16	3.832811	-0.43135
11361.12	10527.79	49583.37	2275.28	0	60833.38	3.660717	-0.4146
14350.01	13119.45	45250.04	2318.891	0	63083.38	3.431628	-0.40389
3061.114	96.36119	35972.25	23627.8	9063.896	24141.69	1.870916	-1.11517
2925.002	108.889	37388.92	25311.13	9291.674	25991.69	2.138944	-1.05221
2966.669	132.5557	55222.27	22161.13	6388.894	37888.92	2.678023	-0.92861
3402.781	195.8613	76805.62	16761.12	2902.78	52527.82	3.179688	-0.79923
3952.781	536.6671	87055.63	12816.68	808.334	59611.16	3.616277	-0.67046
4394.448	1255.279	95000.08	9097.23	0	68638.94	3.910007	-0.56386
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4225.003	2471.113	84555.62	4280.559	0	73000.06	4.214922	-0.49825
5086.115	3644.447	78166.73	3450.003	0	75361.17	4.301837	-0.47013
6680.561	6116.672	72666.72	3222.225	0	76305.62	4.3241	-0.44489
7908.34	8075.006	70527.83	2938.891	0	81777.84	4.312506	-0.42656
3061.114	96.36119	35972.25	23627.8	9063.896	24141.69	1.870916	-1.11517
2925.002	108.889	37388.92	25311.13	9291.674	25991.69	2.138942	-1.05221
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4280.559	400.8337	89361.18	15847.23	808.334	61944.49	3.720313	-0.73787
5238.893	889.7229	100805.6	12877.79	0	73083.39	4.204516	-0.63106
5861.116	1421.946	107333.4	9577.785	0	82861.18	4.607925	-0.59371
5941.671	1675.001	102833.4	7141.672	0	85722.29	4.949741	-0.55274

5602.782	1893.335	99111.19	5591.671	0	90138.96	5.207266	-0.51623
5411.115	2822.224	91166.74	4366.67	0	89194.52	5.378522	-0.48478
5661.116	4197.226	84972.29	3711.114	0	93055.63	5.504735	-0.45672
3061.114	96.36119	35972.25	23627.8	9063.896	24141.69	1.870916	-1.11517
2925.002	108.889	37388.92	25311.13	9291.674	25991.69	2.137968	-1.05339
2930.558	134.7779	55666.71	22627.8	6388.894	38027.81	2.708892	-0.95575
3483.336	258.9447	78416.73	18841.68	2902.78	54000.04	3.336422	-0.87824
4491.67	491.9448	90750.07	17713.9	808.334	64138.94	4.053595	-0.81424
5541.671	929.4452	103361.2	15369.46	0	76916.73	4.837492	-0.72856
5950.005	1322.501	114861.2	12163.9	0	90416.74	5.640415	-0.70926
5891.671	1598.335	121027.9	9408.341	0	99083.41	6.479087	-0.68045
5675.005	1901.668	130472.3	7216.672	0	111639	7.307217	-0.64595
5725.005	2174.446	129472.3	5450.004	0	114666.8	8.052744	-0.60579
6075.005	2550.835	121555.7	4125.003	0	117000.1	8.69777	-0.55226

Radiative forcing (methane)	Radiative forcing (CO2)	Radiative forcing (f-gases)	Radiative forcing (Kyoto gases)	Radiative forcing (nitrous oxide)	GDP	Cropland	Forest	Pasture	Urban area
0.562305	1.689784	0.021105	2.34675	0.155711	5.74E+13	1.55E+09	3.73E+09	3.19E+09	67192000
0.588276	1.837859	0.031102	2.539069	0.167804	6.85E+13	1.58E+09	3.71E+09	3.19E+09	62963563
0.587912	2.126495	0.05629	2.87373	0.188953	1.02E+14	1.53E+09	3.72E+09	3.1E+09	77418556
0.507789	2.286914	0.060184	2.983996	0.203256	1.56E+14	1.52E+09	3.77E+09	3E+09	91698694
0.422359	2.297562	0.047899	2.918372	0.212165	2.23E+14	1.61E+09	3.81E+09	2.91E+09	1.05E+08
0.360978	2.233642	0.040867	2.802596	0.21973	2.91E+14	1.63E+09	3.91E+09	2.79E+09	1.16E+08
0.322647	2.14897	0.037774	2.688533	0.226153	3.56E+14	1.65E+09	4E+09	2.68E+09	1.19E+08
0.302464	2.056453	0.036675	2.583887	0.232355	4.19E+14	1.68E+09	4.08E+09	2.59E+09	1.21E+08
0.285537	1.948056	0.036537	2.467311	0.238767	4.75E+14	1.75E+09	4.14E+09	2.53E+09	1.21E+08
0.26893	1.817973	0.036705	2.329769	0.24532	5.25E+14	1.77E+09	4.2E+09	2.47E+09	1.19E+08
0.253994	1.662189	0.036653	2.167739	0.251879	5.65E+14	1.79E+09	4.23E+09	2.4E+09	1.16E+08
0.562305	1.689784	0.021105	2.34675	0.155711	5.74E+13	1.55E+09	3.73E+09	3.19E+09	67192000
0.588276	1.837859	0.031102	2.539069	0.167804	6.85E+13	1.58E+09	3.71E+09	3.19E+09	62963563
0.593697	2.157672	0.062164	2.915987	0.189224	1.02E+14	1.53E+09	3.72E+09	3.1E+09	77418556
0.530861	2.434354	0.084949	3.177712	0.205083	1.56E+14	1.48E+09	3.77E+09	3E+09	91698694
0.456194	2.624037	0.077491	3.306604	0.215457	2.23E+14	1.51E+09	3.85E+09	2.91E+09	1.05E+08
0.398372	2.722558	0.058852	3.344597	0.222913	2.91E+14	1.52E+09	3.97E+09	2.79E+09	1.16E+08
0.359934	2.748165	0.048949	3.333662	0.229083	3.56E+14	1.55E+09	4.06E+09	2.68E+09	1.19E+08
0.333714	2.721972	0.044354	3.286307	0.234898	4.19E+14	1.6E+09	4.12E+09	2.59E+09	1.21E+08
0.305963	2.642602	0.042279	3.18728	0.241008	4.75E+14	1.72E+09	4.14E+09	2.53E+09	1.21E+08
0.283203	2.514044	0.0413	3.045488	0.248186	5.25E+14	1.82E+09	4.16E+09	2.47E+09	1.19E+08
0.267574	2.38049	0.040553	2.905152	0.255495	5.65E+14	1.77E+09	4.22E+09	2.4E+09	1.16E+08
0.562305	1.689784	0.021105	2.34675	0.155711	5.74E+13	1.55E+09	3.73E+09	3.19E+09	67192000
0.588276	1.837859	0.031102	2.539069	0.167804	6.85E+13	1.58E+09	3.71E+09	3.19E+09	62963563
0.614046	2.165302	0.064886	2.944814	0.190343	1.02E+14	1.54E+09	3.71E+09	3.12E+09	77418556
0.5851	2.480179	0.104262	3.293846	0.20981	1.56E+14	1.5E+09	3.75E+09	3.04E+09	91698694
0.518965	2.759221	0.130879	3.557826	0.224548	2.23E+14	1.53E+09	3.83E+09	2.95E+09	1.05E+08
0.46013	2.986978	0.138963	3.75372	0.234802	2.91E+14	1.54E+09	3.95E+09	2.83E+09	1.16E+08
0.417503	3.15954	0.130103	3.888342	0.242097	3.56E+14	1.54E+09	4.06E+09	2.71E+09	1.19E+08
0.377451	3.268606	0.117908	3.956422	0.247491	4.19E+14	1.56E+09	4.16E+09	2.63E+09	1.21E+08
0.337522	3.293187	0.098625	3.93196	0.251814	4.75E+14	1.6E+09	4.24E+09	2.56E+09	1.21E+08
0.303393	3.224016	0.076575	3.816512	0.256723	5.25E+14	1.74E+09	4.22E+09	2.5E+09	1.19E+08
0.281587	3.098069	0.064914	3.666768	0.263206	5.65E+14	1.84E+09	4.18E+09	2.43E+09	1.16E+08
0.562305	1.689784	0.021105	2.34675	0.155711	5.74E+13	1.55E+09	3.73E+09	3.19E+09	67192000
0.588276	1.837859	0.031102	2.539069	0.167804	6.85E+13	1.58E+09	3.71E+09	3.19E+09	62963563
0.616108	2.166663	0.065143	2.948266	0.190418	1.02E+14	1.54E+09	3.7E+09	3.13E+09	77418556
0.600012	2.491989	0.107422	3.322438	0.210713	1.56E+14	1.51E+09	3.74E+09	3.06E+09	91698694

0.558577	2.800595	0.150954	3.656641	0.228122	2.23E+14	1.54E+09	3.8E+09	2.98E+09	1.05E+08
0.517918	3.081786	0.193118	3.960117	0.242929	2.91E+14	1.55E+09	3.87E+09	2.86E+09	1.16E+08
0.482021	3.330038	0.227216	4.22383	0.254919	3.56E+14	1.55E+09	3.94E+09	2.74E+09	1.19E+08
0.441072	3.536311	0.241699	4.418094	0.263369	4.19E+14	1.56E+09	4.01E+09	2.66E+09	1.21E+08
0.395604	3.681662	0.225876	4.514041	0.268592	4.75E+14	1.61E+09	4.06E+09	2.59E+09	1.21E+08
0.351238	3.76573	0.206082	4.543719	0.271865	5.25E+14	1.63E+09	4.11E+09	2.52E+09	1.19E+08
0.31245	3.801884	0.189608	4.532638	0.274216	5.65E+14	1.62E+09	4.16E+09	2.46E+09	1.16E+08
0.562305	1.689784	0.021105	2.34675	0.155711	5.74E+13	1.55E+09	3.73E+09	3.19E+09	67192000
0.588276	1.837859	0.031102	2.539069	0.167804	6.85E+13	1.58E+09	3.71E+09	3.19E+09	62963563
0.620427	2.167961	0.06525	2.953577	0.190641	1.02E+14	1.55E+09	3.7E+09	3.14E+09	77418556
0.633706	2.504503	0.108899	3.366587	0.212134	1.56E+14	1.52E+09	3.7E+09	3.08E+09	91698694
0.640193	2.835057	0.159799	3.773374	0.231935	2.23E+14	1.55E+09	3.73E+09	3.01E+09	1.05E+08
0.631824	3.141208	0.212557	4.14256	0.249349	2.91E+14	1.57E+09	3.78E+09	2.89E+09	1.16E+08
0.61045	3.421694	0.257734	4.464824	0.26418	3.56E+14	1.57E+09	3.84E+09	2.78E+09	1.19E+08
0.581716	3.678986	0.297662	4.750294	0.276938	4.19E+14	1.58E+09	3.89E+09	2.69E+09	1.21E+08
0.542534	3.894973	0.334758	4.98104	0.288024	4.75E+14	1.61E+09	3.92E+09	2.62E+09	1.21E+08
0.49836	4.067145	0.365317	5.155511	0.297451	5.25E+14	1.63E+09	3.95E+09	2.55E+09	1.19E+08
0.459471	4.210662	0.383124	5.291111	0.30491	5.65E+14	1.6E+09	4E+09	2.49E+09	1.16E+08
0.562305	1.689784	0.021105	2.34675	0.155711	5.65E+13	1.54E+09	3.92E+09	3.43E+09	
0.588276	1.837859	0.031102	2.539069	0.167804	6.75E+13	1.55E+09	3.89E+09	3.42E+09	
0.61707	2.151473	0.06133	2.930644	0.190979	1.01E+14	1.61E+09	3.91E+09	3.38E+09	
0.58715	2.351585	0.077088	3.14249	0.212475	1.41E+14	1.68E+09	3.96E+09	3.36E+09	
0.509574	2.396929	0.075699	3.137563	0.22977	1.81E+14	1.73E+09	4.06E+09	3.16E+09	
0.435621	2.364166	0.076608	3.053658	0.240821	2.23E+14	1.76E+09	4.19E+09	2.95E+09	
0.380312	2.285698	0.079394	2.936336	0.246385	2.69E+14	1.8E+09	4.32E+09	2.75E+09	
0.338259	2.169025	0.082533	2.788741	0.248219	3.21E+14	1.87E+09	4.42E+09	2.58E+09	
0.301909	2.020294	0.084975	2.610428	0.247229	3.78E+14	1.91E+09	4.49E+09	2.44E+09	
0.271782	1.858256	0.086585	2.421552	0.244504	4.38E+14	1.93E+09	4.55E+09	2.33E+09	
0.249517	1.701561	0.087789	2.242835	0.240289	5.05E+14	1.94E+09	4.61E+09	2.24E+09	
0.562305	1.689784	0.021105	2.34675	0.155711	5.65E+13	1.54E+09	3.92E+09	3.43E+09	
0.588276	1.837859	0.031102	2.539069	0.167804	6.75E+13	1.55E+09	3.89E+09	3.42E+09	
0.617437	2.149903	0.061264	2.929337	0.190994	1.01E+14	1.62E+09	3.9E+09	3.38E+09	
0.60655	2.413017	0.078293	3.222621	0.213422	1.42E+14	1.68E+09	3.92E+09	3.39E+09	
0.559263	2.595962	0.080345	3.387617	0.233756	1.84E+14	1.73E+09	3.96E+09	3.36E+09	
0.496306	2.693107	0.084704	3.451632	0.249976	2.29E+14	1.78E+09	4.05E+09	3.28E+09	
0.449361	2.713744	0.089193	3.44877	0.262045	2.77E+14	1.82E+09	4.15E+09	3.12E+09	
0.420164	2.673226	0.092784	3.395633	0.270751	3.31E+14	1.89E+09	4.24E+09	2.98E+09	
0.395895	2.57974	0.096069	3.289546	0.275577	3.9E+14	1.96E+09	4.33E+09	2.85E+09	
0.366439	2.461945	0.098798	3.150762	0.277001	4.54E+14	2.01E+09	4.41E+09	2.73E+09	
0.33553	2.341671	0.101286	3.005621	0.27603	5.25E+14	2.04E+09	4.48E+09	2.61E+09	
0.562305	1.689784	0.021105	2.34675	0.155711	5.65E+13	1.54E+09	3.92E+09	3.43E+09	
0.588276	1.837859	0.031102	2.539069	0.167804	6.75E+13	1.55E+09	3.89E+09	3.42E+09	
0.618688	2.156237	0.06126	2.936828	0.191089	1.01E+14	1.62E+09	3.88E+09	3.4E+09	
0.621345	2.467845	0.083669	3.296106	0.214084	1.43E+14	1.66E+09	3.88E+09	3.43E+09	
0.592793	2.749819	0.090979	3.582878	0.235924	1.85E+14	1.72E+09	3.88E+09	3.43E+09	
0.537515	2.97831	0.094226	3.786408	0.254871	2.3E+14	1.77E+09	3.93E+09	3.39E+09	
0.488544	3.133864	0.09806	3.919573	0.270427	2.79E+14	1.82E+09	4.01E+09	3.33E+09	

0.459203	3.206403	0.103224	3.984654	0.282841	3.34E+14	1.87E+09	4.09E+09	3.26E+09	
0.441564	3.211701	0.106661	3.986807	0.291311	3.94E+14	1.94E+09	4.16E+09	3.15E+09	
0.425481	3.168402	0.108445	3.936196	0.29594	4.6E+14	1.99E+09	4.25E+09	3.02E+09	
0.405663	3.097801	0.110579	3.852951	0.298074	5.32E+14	2.02E+09	4.33E+09	2.9E+09	
0.562305	1.689784	0.021105	2.34675	0.155711	5.65E+13	1.54E+09	3.92E+09	3.43E+09	
0.588276	1.837859	0.031102	2.539069	0.167804	6.75E+13	1.55E+09	3.89E+09	3.42E+09	
0.619873	2.159908	0.061273	2.94157	0.191135	1.01E+14	1.62E+09	3.88E+09	3.41E+09	
0.627489	2.487764	0.087113	3.324946	0.21432	1.43E+14	1.66E+09	3.86E+09	3.44E+09	
0.614632	2.812848	0.098791	3.673209	0.236786	1.86E+14	1.71E+09	3.85E+09	3.45E+09	
0.578009	3.118515	0.101803	3.970963	0.257099	2.31E+14	1.76E+09	3.87E+09	3.44E+09	
0.532436	3.384324	0.103702	4.217531	0.274837	2.8E+14	1.8E+09	3.93E+09	3.42E+09	
0.499299	3.598281	0.108015	4.422663	0.289969	3.36E+14	1.85E+09	4E+09	3.37E+09	
0.477175	3.749493	0.112576	4.570861	0.301271	3.96E+14	1.91E+09	4.06E+09	3.31E+09	
0.46059	3.82146	0.116856	4.640268	0.308584	4.63E+14	1.95E+09	4.12E+09	3.24E+09	
0.449891	3.832534	0.119682	4.649403	0.312947	5.35E+14	1.98E+09	4.2E+09	3.14E+09	
0.562305	1.689784	0.021105	2.34675	0.155711	5.65E+13	1.54E+09	3.92E+09	3.43E+09	
0.588276	1.837859	0.031102	2.539069	0.167804	6.75E+13	1.55E+09	3.89E+09	3.42E+09	
0.621315	2.160564	0.061275	2.94351	0.191189	1.01E+14	1.62E+09	3.87E+09	3.41E+09	
0.636997	2.498892	0.091407	3.348699	0.214542	1.43E+14	1.66E+09	3.86E+09	3.45E+09	
0.6457	2.858792	0.119426	3.766984	0.237486	1.86E+14	1.7E+09	3.84E+09	3.49E+09	
0.637477	3.234801	0.148527	4.186449	0.258855	2.31E+14	1.75E+09	3.85E+09	3.5E+09	
0.614447	3.61311	0.173135	4.589233	0.278363	2.8E+14	1.81E+09	3.86E+09	3.5E+09	
0.590103	3.979853	0.183224	4.963085	0.296147	3.37E+14	1.85E+09	3.88E+09	3.5E+09	
0.56345	4.332558	0.17176	5.296761	0.311316	3.98E+14	1.88E+09	3.91E+09	3.49E+09	
0.535615	4.67138	0.157098	5.609974	0.324115	4.65E+14	1.9E+09	3.96E+09	3.47E+09	
0.507884	4.994292	0.151042	5.91444	0.335382	5.38E+14	1.91E+09	4.03E+09	3.43E+09	
0.562305	1.689784	0.021105	2.34675	0.155711	5.65E+13	1.54E+09	3.92E+09	3.43E+09	
0.588276	1.837859	0.031102	2.539069	0.167804	6.75E+13	1.55E+09	3.89E+09	3.42E+09	
0.624748	2.159722	0.061417	2.945842	0.191292	1.01E+14	1.62E+09	3.87E+09	3.42E+09	
0.647046	2.500869	0.093018	3.361601	0.215286	1.43E+14	1.66E+09	3.86E+09	3.45E+09	
0.664906	2.875136	0.122854	3.805414	0.239765	1.86E+14	1.71E+09	3.84E+09	3.5E+09	
0.676128	3.280468	0.156046	4.277484	0.263741	2.31E+14	1.75E+09	3.83E+09	3.53E+09	
0.685959	3.706119	0.192871	4.771584	0.286982	2.81E+14	1.81E+09	3.84E+09	3.56E+09	
0.695531	4.143406	0.23523	5.28189	0.30948	3.37E+14	1.86E+09	3.84E+09	3.58E+09	
0.699882	4.607236	0.283043	5.818905	0.331141	3.98E+14	1.89E+09	3.85E+09	3.6E+09	
0.698119	5.1021	0.334059	6.384739	0.352599	4.66E+14	1.92E+09	3.85E+09	3.62E+09	
0.688933	5.608091	0.386994	6.957501	0.374267	5.39E+14	1.94E+09	3.88E+09	3.63E+09	
0.562305	1.689784	0.021105	2.34675	0.155711	5.47E+13	1.53E+09	3.9E+09	3.38E+09	61494300
0.588276	1.837859	0.031102	2.539069	0.167804	6.48E+13	1.57E+09	3.85E+09	3.47E+09	61494300
0.645306	2.19016	0.055151	2.988596	0.192341	9.74E+13	1.66E+09	3.75E+09	3.61E+09	61494300
0.704065	2.564968	0.067003	3.45152	0.218497	1.3E+14	1.74E+09	3.68E+09	3.67E+09	61494300
0.693543	2.838265	0.066193	3.736247	0.23971	1.5E+14	1.81E+09	3.72E+09	3.69E+09	61494300
0.618935	2.980298	0.058681	3.82201	0.254578	1.66E+14	1.93E+09	3.71E+09	3.68E+09	61494300
0.568626	3.057819	0.048947	3.861946	0.269637	1.8E+14	2.05E+09	3.66E+09	3.67E+09	61494300
0.548939	3.082726	0.043026	3.878947	0.284447	1.95E+14	2.16E+09	3.65E+09	3.68E+09	61494300
0.537888	3.060543	0.039115	3.857332	0.298355	2.09E+14	2.23E+09	3.68E+09	3.68E+09	61494300
0.53274	3.006709	0.036354	3.809533	0.311542	2.25E+14	2.27E+09	3.71E+09	3.66E+09	61494300

0.531503	2.932619	0.034317	3.744965	0.324156	2.42E+14	2.3E+09	3.75E+09	3.63E+09	61494300
0.562305	1.689784	0.021105	2.34675	0.155711	5.47E+13	1.53E+09	3.9E+09	3.38E+09	61494300
0.588276	1.837859	0.031102	2.539069	0.167804	6.48E+13	1.57E+09	3.85E+09	3.47E+09	61494300
0.645296	2.190167	0.059735	2.993178	0.192341	9.74E+13	1.66E+09	3.75E+09	3.61E+09	61494300
0.708194	2.578311	0.087233	3.489152	0.219037	1.3E+14	1.74E+09	3.67E+09	3.67E+09	61494300
0.709338	2.919511	0.098862	3.866522	0.242602	1.53E+14	1.81E+09	3.65E+09	3.68E+09	61494300
0.658075	3.176725	0.092152	4.091898	0.261188	1.7E+14	1.94E+09	3.61E+09	3.68E+09	61494300
0.621991	3.346415	0.084662	4.241348	0.279211	1.83E+14	2.1E+09	3.54E+09	3.68E+09	61494300
0.607819	3.442875	0.08233	4.34081	0.296633	1.99E+14	2.18E+09	3.52E+09	3.69E+09	61494300
0.609061	3.512092	0.080073	4.426237	0.314041	2.16E+14	2.25E+09	3.5E+09	3.7E+09	61494300
0.613461	3.558569	0.071974	4.485369	0.331042	2.33E+14	2.32E+09	3.51E+09	3.69E+09	61494300
0.613692	3.5745	0.065749	4.511286	0.347056	2.51E+14	2.37E+09	3.54E+09	3.67E+09	61494300
0.562305	1.689784	0.021105	2.34675	0.155711	5.47E+13	1.53E+09	3.9E+09	3.38E+09	61494300
0.588276	1.837859	0.031102	2.539069	0.167804	6.48E+13	1.57E+09	3.85E+09	3.47E+09	61494300
0.645293	2.190169	0.061331	2.994774	0.192341	9.74E+13	1.66E+09	3.75E+09	3.61E+09	61494300
0.708719	2.579624	0.094649	3.498398	0.219105	1.3E+14	1.74E+09	3.67E+09	3.67E+09	61494300
0.724567	2.949284	0.120945	3.932879	0.244117	1.53E+14	1.82E+09	3.63E+09	3.68E+09	61494300
0.697358	3.281723	0.137246	4.280054	0.265752	1.72E+14	1.94E+09	3.57E+09	3.68E+09	61494300
0.691516	3.601867	0.150688	4.630892	0.287988	1.87E+14	2.08E+09	3.47E+09	3.69E+09	61494300
0.702423	3.89489	0.157224	4.962386	0.310621	2.04E+14	2.21E+09	3.39E+09	3.7E+09	61494300
0.711822	4.136157	0.15372	5.230225	0.332683	2.21E+14	2.31E+09	3.35E+09	3.71E+09	61494300
0.724909	4.339095	0.147349	5.459772	0.354503	2.4E+14	2.39E+09	3.31E+09	3.71E+09	61494300
0.74118	4.524208	0.143976	5.677172	0.376291	2.62E+14	2.47E+09	3.27E+09	3.7E+09	61494300
0.562305	1.689784	0.021105	2.34675	0.155711	5.47E+13	1.53E+09	3.9E+09	3.38E+09	61494300
0.588276	1.837859	0.031102	2.539069	0.167804	6.48E+13	1.57E+09	3.85E+09	3.47E+09	61494300
0.649781	2.200611	0.061429	3.009734	0.192934	9.74E+13	1.66E+09	3.75E+09	3.61E+09	61494300
0.722132	2.620565	0.096203	3.554564	0.22134	1.3E+14	1.74E+09	3.67E+09	3.67E+09	61494300
0.791048	3.066355	0.129301	4.122755	0.251888	1.55E+14	1.81E+09	3.62E+09	3.67E+09	61494300
0.852488	3.525137	0.160367	4.696629	0.283541	1.74E+14	1.89E+09	3.57E+09	3.68E+09	61494300
0.908723	3.989162	0.187713	5.268413	0.316027	1.9E+14	1.98E+09	3.51E+09	3.68E+09	61494300
0.961772	4.456451	0.21072	5.837237	0.349348	2.08E+14	2.07E+09	3.46E+09	3.7E+09	61494300
1.013292	4.928548	0.231493	6.407978	0.383323	2.27E+14	2.15E+09	3.41E+09	3.71E+09	61494300
1.063375	5.408881	0.251077	6.984998	0.41776	2.47E+14	2.21E+09	3.37E+09	3.71E+09	61494300
1.112223	5.901405	0.270318	7.573102	0.45249	2.7E+14	2.28E+09	3.33E+09	3.7E+09	61494300

0.588276	1.837859	0.031102	2.539069	0.167804	6.69E+13	1.5E+09	4.09E+09	3.25E+09	61326101
0.634235	2.166646	0.04695	2.946263	0.191165	9.98E+13	1.53E+09	4.08E+09	3.29E+09	61326101
0.642523	2.392256	0.049387	3.20342	0.213207	1.42E+14	1.62E+09	4.24E+09	3.22E+09	61326101
0.636712	2.480844	0.046121	3.305027	0.234446	1.82E+14	1.77E+09	4.31E+09	3.19E+09	61326101
0.645415	2.5265	0.040973	3.375443	0.256934	2.19E+14	1.95E+09	4.31E+09	3.19E+09	61326101
0.65195	2.539541	0.036665	3.413246	0.28043	2.52E+14	2.22E+09	4.19E+09	3.18E+09	61326101
0.652158	2.505161	0.035044	3.401676	0.304684	2.82E+14	2.48E+09	4.06E+09	3.17E+09	61326101
0.640923	2.393365	0.034808	3.304191	0.328812	3.07E+14	2.69E+09	3.98E+09	3.12E+09	61326101
0.621144	2.197098	0.035395	3.114242	0.351412	3.3E+14	2.83E+09	3.94E+09	3.06E+09	61326101
0.600635	1.928294	0.036579	2.849794	0.372076	3.52E+14	2.94E+09	3.92E+09	3E+09	61326101

0.588276	1.837859	0.031102	2.539069	0.167804	6.69E+13	1.5E+09	4.09E+09	3.25E+09	61326101
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0.634235	2.166646	0.04695	2.946263	0.191165	9.98E+13	1.53E+09	4.08E+09	3.29E+09	61326101
0.650287	2.457222	0.049376	3.275549	0.213759	1.41E+14	1.57E+09	4.19E+09	3.28E+09	61326101
0.654695	2.662389	0.046109	3.503371	0.235922	1.82E+14	1.64E+09	4.28E+09	3.27E+09	61326101
0.665937	2.788353	0.040958	3.656625	0.258777	2.19E+14	1.72E+09	4.34E+09	3.29E+09	61326101
0.67359	2.85889	0.036683	3.752758	0.28212	2.52E+14	1.88E+09	4.29E+09	3.31E+09	61326101
0.678121	2.898618	0.035066	3.818522	0.30591	2.82E+14	2.08E+09	4.2E+09	3.31E+09	61326101
0.674256	2.893042	0.034803	3.833601	0.330125	3.07E+14	2.35E+09	4.09E+09	3.27E+09	61326101
0.660414	2.813067	0.03531	3.766428	0.354222	3.3E+14	2.57E+09	4E+09	3.2E+09	61326101
0.640362	2.653878	0.036318	3.613899	0.376975	3.52E+14	2.74E+09	3.96E+09	3.12E+09	61326101
0.588276	1.837859	0.031102	2.539069	0.167804	6.69E+13	1.5E+09	4.09E+09	3.25E+09	61326101
0.634235	2.166646	0.04695	2.946263	0.191165	9.98E+13	1.53E+09	4.08E+09	3.29E+09	61326101
0.656481	2.48289	0.049463	3.307126	0.214299	1.41E+14	1.57E+09	4.15E+09	3.3E+09	61326101
0.669348	2.75507	0.046301	3.610373	0.237556	1.82E+14	1.61E+09	4.22E+09	3.31E+09	61326101
0.684668	2.960569	0.041178	3.847518	0.26126	2.19E+14	1.66E+09	4.3E+09	3.33E+09	61326101
0.692696	3.091451	0.036928	4.00475	0.285015	2.52E+14	1.75E+09	4.29E+09	3.36E+09	61326101
0.695985	3.170621	0.035329	4.10881	0.308699	2.82E+14	1.87E+09	4.26E+09	3.39E+09	61326101
0.696918	3.215871	0.035032	4.178512	0.332653	3.07E+14	1.91E+09	4.22E+09	3.43E+09	61326101
0.699614	3.251154	0.035451	4.240631	0.356771	3.3E+14	1.93E+09	4.21E+09	3.45E+09	61326101
0.703168	3.286504	0.036296	4.303723	0.380637	3.52E+14	2E+09	4.19E+09	3.44E+09	61326101
0.588276	1.837859	0.031102	2.539069	0.167804	6.69E+13	1.5E+09	4.09E+09	3.25E+09	61326101
0.634235	2.166646	0.04695	2.946263	0.191165	9.98E+13	1.53E+09	4.08E+09	3.29E+09	61326101
0.682513	2.521626	0.050001	3.371352	0.217052	1.41E+14	1.58E+09	4.07E+09	3.34E+09	61326101
0.73123	2.893426	0.047493	3.811703	0.246572	1.82E+14	1.63E+09	4.06E+09	3.39E+09	61326101
0.76445	3.250025	0.042702	4.221762	0.276499	2.19E+14	1.65E+09	4.07E+09	3.44E+09	61326101
0.782969	3.577964	0.038865	4.590759	0.305606	2.52E+14	1.69E+09	4.07E+09	3.49E+09	61326101
0.791254	3.872664	0.037667	4.918909	0.333192	2.82E+14	1.7E+09	4.08E+09	3.54E+09	61326101
0.788514	4.1144	0.037705	5.184012	0.358857	3.07E+14	1.71E+09	4.11E+09	3.57E+09	61326101
0.778293	4.290926	0.038337	5.376374	0.382773	3.3E+14	1.71E+09	4.16E+09	3.57E+09	61326101
0.766302	4.410304	0.039267	5.509168	0.405481	3.52E+14	1.72E+09	4.21E+09	3.56E+09	61326101
0.562305	1.689784	0.021105	2.34675	0.155711	5.67E+13	1.52E+09	4.08E+09	3.31E+09	55230223
0.588276	1.837859	0.031102	2.539069	0.167804	6.69E+13	1.5E+09	4.09E+09	3.25E+09	61326101
0.64437	2.176313	0.06181	2.980581	0.192313	9.98E+13	1.53E+09	4.08E+09	3.29E+09	61326101
0.714351	2.556578	0.10475	3.490897	0.219748	1.41E+14	1.58E+09	4.06E+09	3.34E+09	61326101
0.787469	2.968715	0.150745	4.041817	0.250196	1.82E+14	1.64E+09	4.02E+09	3.39E+09	61326101
0.842614	3.380591	0.190665	4.573054	0.282631	2.19E+14	1.68E+09	3.99E+09	3.46E+09	61326101
0.880003	3.780524	0.225359	5.07309	0.316172	2.52E+14	1.73E+09	3.95E+09	3.52E+09	61326101
0.908121	4.162736	0.25527	5.543113	0.350109	2.82E+14	1.75E+09	3.92E+09	3.59E+09	61326101
0.921773	4.508214	0.280093	5.959064	0.384125	3.07E+14	1.77E+09	3.9E+09	3.64E+09	61326101
0.923408	4.816006	0.299727	6.321598	0.417839	3.3E+14	1.77E+09	3.89E+09	3.67E+09	61326101
0.920803	5.100397	0.314992	6.652367	0.451172	3.52E+14	1.76E+09	3.89E+09	3.69E+09	61326101
0.562305	1.689784	0.021105	2.34675	0.155711	5.67E+13	1.47E+09	4.19E+09	3.12E+09	1.33E+08
0.588276	1.837859	0.031102	2.539069	0.167804	6.76E+13	1.52E+09	4.17E+09	3.09E+09	1.33E+08
0.627201	2.162293	0.061349	2.950228	0.191084	1.02E+14	1.62E+09	4.16E+09	2.95E+09	1.33E+08
0.592344	2.467259	0.071906	3.256308	0.21137	1.63E+14	1.68E+09	4.16E+09	2.89E+09	1.33E+08
0.501608	2.654811	0.057214	3.369834	0.22944	2.47E+14	1.88E+09	4.16E+09	2.66E+09	1.33E+08

0.434913	2.641123	0.045271	3.309223	0.251369	3.38E+14	2.21E+09	4.17E+09	2.31E+09	1.33E+08
0.391864	2.460249	0.039636	3.109441	0.274838	4.41E+14	2.29E+09	4.17E+09	2.22E+09	1.33E+08
0.366445	2.221032	0.037256	2.865983	0.294672	5.6E+14	2.35E+09	4.17E+09	2.15E+09	1.33E+08
0.348357	1.992062	0.03648	2.637918	0.311793	6.87E+14	2.38E+09	4.17E+09	2.09E+09	1.33E+08
0.329917	1.771622	0.036292	2.416643	0.326887	8.19E+14	2.37E+09	4.18E+09	2.01E+09	1.33E+08
0.307836	1.551348	0.036189	2.189296	0.338768	9.6E+14	2.27E+09	4.18E+09	2.01E+09	1.33E+08
0.562305	1.689784	0.021105	2.34675	0.155711	5.67E+13	1.47E+09	4.19E+09	3.12E+09	1.33E+08
0.588276	1.837859	0.031102	2.539069	0.167804	6.76E+13	1.52E+09	4.15E+09	3.08E+09	1.33E+08
0.627376	2.161606	0.061344	2.949634	0.191032	1.02E+14	1.63E+09	4.14E+09	2.99E+09	1.33E+08
0.617671	2.497531	0.071894	3.309226	0.212427	1.65E+14	1.68E+09	4.14E+09	2.93E+09	1.33E+08
0.557367	2.800359	0.05732	3.563816	0.230199	2.55E+14	1.77E+09	4.14E+09	2.81E+09	1.33E+08
0.494354	2.987606	0.045232	3.701127	0.246109	3.52E+14	2E+09	4.14E+09	2.59E+09	1.33E+08
0.450187	3.017384	0.039547	3.705502	0.264079	4.56E+14	2.23E+09	4.14E+09	2.34E+09	1.33E+08
0.415291	2.917297	0.037128	3.592801	0.283663	5.77E+14	2.3E+09	4.14E+09	2.27E+09	1.33E+08
0.381109	2.749864	0.036332	3.413017	0.301282	7.03E+14	2.34E+09	4.14E+09	2.23E+09	1.33E+08
0.345932	2.545172	0.036133	3.19333	0.316512	8.34E+14	2.37E+09	4.15E+09	2.2E+09	1.33E+08
0.315616	2.323783	0.036013	2.959306	0.329877	9.75E+14	2.39E+09	4.15E+09	2.18E+09	1.33E+08
0.562305	1.689784	0.021105	2.34675	0.155711	5.67E+13	1.47E+09	4.19E+09	3.12E+09	1.33E+08
0.588276	1.837859	0.031102	2.539069	0.167804	6.76E+13	1.52E+09	4.15E+09	3.08E+09	1.33E+08
0.627381	2.161538	0.062255	2.950481	0.191032	1.02E+14	1.63E+09	4.14E+09	2.99E+09	1.33E+08
0.638325	2.505079	0.087044	3.350013	0.2129	1.65E+14	1.67E+09	4.14E+09	2.94E+09	1.33E+08
0.60739	2.845634	0.089641	3.68588	0.232	2.56E+14	1.74E+09	4.14E+09	2.86E+09	1.33E+08
0.552155	3.125341	0.073499	3.916871	0.246539	3.55E+14	1.78E+09	4.14E+09	2.82E+09	1.33E+08
0.500423	3.316805	0.055815	4.057759	0.257783	4.63E+14	1.92E+09	4.14E+09	2.67E+09	1.33E+08
0.459066	3.401235	0.047303	4.110856	0.270249	5.84E+14	2.06E+09	4.14E+09	2.53E+09	1.33E+08
0.419591	3.373447	0.043223	4.059331	0.284278	7.13E+14	2.19E+09	4.14E+09	2.37E+09	1.33E+08
0.377866	3.249438	0.041136	3.912185	0.298839	8.47E+14	2.22E+09	4.15E+09	2.33E+09	1.33E+08
0.336914	3.068758	0.039872	3.70842	0.311975	9.87E+14	2.23E+09	4.15E+09	2.32E+09	1.33E+08
0.562305	1.689784	0.021105	2.34675	0.155711	5.67E+13	1.47E+09	4.19E+09	3.12E+09	1.33E+08
0.588276	1.837859	0.031102	2.539069	0.167804	6.76E+13	1.52E+09	4.15E+09	3.08E+09	1.33E+08
0.627381	2.161493	0.062795	2.950976	0.191032	1.02E+14	1.63E+09	4.14E+09	2.99E+09	1.33E+08
0.639405	2.507651	0.100062	3.366648	0.213023	1.65E+14	1.67E+09	4.14E+09	2.94E+09	1.33E+08
0.621986	2.864143	0.12411	3.752031	0.232722	2.56E+14	1.74E+09	4.14E+09	2.87E+09	1.33E+08
0.57929	3.186294	0.128383	4.058074	0.248759	3.57E+14	1.77E+09	4.14E+09	2.83E+09	1.33E+08
0.526813	3.446533	0.119182	4.276482	0.260894	4.67E+14	1.82E+09	4.14E+09	2.77E+09	1.33E+08
0.487433	3.632592	0.1146	4.435096	0.271628	5.9E+14	1.89E+09	4.14E+09	2.7E+09	1.33E+08
0.455517	3.759218	0.109984	4.540051	0.281808	7.23E+14	1.92E+09	4.14E+09	2.66E+09	1.33E+08
0.420285	3.839908	0.089942	4.57938	0.290555	8.63E+14	1.93E+09	4.15E+09	2.61E+09	1.33E+08
0.379409	3.896835	0.070419	4.588187	0.296845	1.01E+15	1.93E+09	4.15E+09	2.61E+09	1.33E+08
0.562305	1.689784	0.021105	2.34675	0.155711	5.67E+13	1.47E+09	4.19E+09	3.12E+09	1.33E+08
0.588276	1.837859	0.031102	2.539069	0.167804	6.76E+13	1.52E+09	4.15E+09	3.08E+09	1.33E+08
0.627378	2.161601	0.062935	2.951223	0.191032	1.02E+14	1.63E+09	4.14E+09	2.99E+09	1.33E+08
0.654702	2.524489	0.103986	3.401029	0.213597	1.65E+14	1.67E+09	4.14E+09	2.94E+09	1.33E+08
0.673984	2.940057	0.139465	3.890039	0.235117	2.58E+14	1.76E+09	4.14E+09	2.86E+09	1.33E+08
0.674274	3.371866	0.166357	4.36748	0.25361	3.61E+14	1.79E+09	4.14E+09	2.83E+09	1.33E+08
0.646346	3.789988	0.190039	4.79972	0.267862	4.72E+14	1.79E+09	4.14E+09	2.82E+09	1.33E+08
0.595399	4.166272	0.210778	5.1646	0.279172	5.96E+14	1.79E+09	4.14E+09	2.81E+09	1.33E+08

0.529563	4.487809	0.219073	5.447005	0.287904	7.29E+14	1.79E+09	4.14E+09	2.81E+09	1.33E+08
0.466334	4.754666	0.196613	5.643355	0.293804	8.7E+14	1.78E+09	4.15E+09	2.8E+09	1.33E+08
0.414488	4.979989	0.158048	5.788432	0.296367	1.02E+15	1.77E+09	4.15E+09	2.8E+09	1.33E+08
0.562305	1.689784	0.021105	2.34675	0.155711	5.67E+13	1.47E+09	4.19E+09	3.12E+09	1.33E+08
0.588276	1.837859	0.031102	2.539069	0.167804	6.76E+13	1.52E+09	4.17E+09	3.09E+09	1.33E+08
0.637125	2.192407	0.065428	2.995137	0.193335	1.02E+14	1.65E+09	4.1E+09	2.99E+09	1.33E+08
0.698243	2.62967	0.11271	3.560156	0.22169	1.66E+14	1.72E+09	4.01E+09	2.99E+09	1.33E+08
0.787532	3.157347	0.161101	4.24101	0.250347	2.6E+14	1.81E+09	3.97E+09	2.94E+09	1.33E+08
0.884166	3.764428	0.209311	5.005437	0.277114	3.65E+14	1.85E+09	3.95E+09	2.94E+09	1.33E+08
0.948753	4.446783	0.262861	5.820303	0.301035	4.78E+14	1.86E+09	3.94E+09	2.93E+09	1.33E+08
0.974094	5.186523	0.321047	6.661779	0.322993	6.06E+14	1.87E+09	3.94E+09	2.92E+09	1.33E+08
0.969416	5.947262	0.373256	7.490486	0.342737	7.41E+14	1.87E+09	3.96E+09	2.91E+09	1.33E+08
0.939662	6.673673	0.405154	8.240856	0.360152	8.82E+14	1.85E+09	3.97E+09	2.85E+09	1.33E+08
0.895933	7.326991	0.415763	8.88191	0.374544	1.03E+15	1.79E+09	3.97E+09	2.84E+09	1.33E+08

Populatio n	Primary energy	Primary energy (kWh)	Primary energy (biomass)	Primary energy (biomass, CCS)	Primary energy (biomass, no CCS)	Primary energy (coal)	Primary energy (coal, CCS)	Primary energy (coal, no CCS)	Primary energy (fossil)
6.53E+09	127506.5	1.28E+14	12189.23	0	12189.23	32633.64	0	32633.64	109509.2
6.92E+09	140522.9	1.41E+14	14643.98	0	14643.98	40273.48	0	40273.48	119306.7
7.58E+09	134227.2	1.34E+14	11990.98	140.9918	11849.98	34527.19	120.6701	34406.53	113206.1
8.06E+09	110156.5	1.1E+14	20613.99	3021.166	17592.83	16470.12	953.0302	15517.09	79128.61
8.39E+09	111005.6	1.11E+14	29409.22	10696.46	18712.75	8282.232	2887.677	5394.557	61573.77
8.53E+09	119748.8	1.2E+14	34317.82	12791.2	21526.62	6841.367	4424.162	2417.204	57092.62
8.49E+09	128479.7	1.28E+14	40222.34	15553.98	24668.35	6930.714	5514.59	1416.125	54961.22
8.3E+09	137459.5	1.37E+14	47747.57	20259.06	27488.51	7330.331	6142.322	1188.01	54024.19
7.97E+09	140298.4	1.4E+14	56347.81	27356.82	28991	6457.594	5491.521	966.0736	44656.66
7.51E+09	137720.8	1.38E+14	62194.07	34645.58	27548.49	4876.918	4085.85	791.0651	33590.62
6.96E+09	136097.9	1.36E+14	70508.27	45113.31	25394.95	3255.958	2618.423	637.5341	25282.96
6.53E+09	127506.5	1.28E+14	12189.23	0	12189.23	32633.64	0	32633.64	109509.2
6.92E+09	140522.9	1.41E+14	14643.98	0	14643.98	40273.48	0	40273.48	119306.7
7.58E+09	151275.3	1.51E+14	11014.77	0	11014.77	42285.98	2.84E-09	42285.98	131123.7
8.06E+09	154763.2	1.55E+14	12389.8	52.76076	12337.04	36780.56	1335.672	35444.89	129781.9
8.39E+09	153665.8	1.54E+14	18131.36	1751.949	16379.42	26951.9	5832.091	21119.81	116841.1
8.53E+09	153389.3	1.53E+14	23464.24	4756.71	18707.53	18539.14	8407.348	10131.79	102672.9
8.49E+09	158911.4	1.59E+14	32872.1	10304.86	22567.23	15014.98	11706.57	3308.408	90941.37
8.3E+09	158221.8	1.58E+14	41543.3	16763.94	24779.36	14367.71	12411.99	1955.721	76645.46
7.97E+09	157879	1.58E+14	55793.83	28655.77	27138.04	12578.08	11054.59	1523.491	59787.71
7.51E+09	158289.8	1.58E+14	66638.52	39165.2	27473.31	11261.57	10030.36	1231.206	49973.56
6.96E+09	156394.2	1.56E+14	62781.53	36276.28	26505.25	8338.345	7432.556	905.7888	46627.2
6.53E+09	127506.5	1.28E+14	12189.23	0	12189.23	32633.64	0	32633.64	109509.2
6.92E+09	140525.9	1.41E+14	14646.92	0	14646.92	40273.48	0	40273.48	119306.7
7.58E+09	155715.4	1.56E+14	11252.4	7.88E-23	11252.4	44046.31	7.93E-12	44046.31	135275.6
8.06E+09	169845.2	1.7E+14	13093.22	7.81E-23	13093.22	44899.51	2.477002	44897.04	144792.9
8.39E+09	178956.8	1.79E+14	18000.32	0.123326	18000.2	40592.53	53.12379	40539.39	144226.8
8.53E+09	184000.4	1.84E+14	20752.4	5.017215	20747.38	32955.61	529.9107	32425.69	137958.8
8.49E+09	187263.1	1.87E+14	24465.51	253.6492	24211.86	27213.13	2370.079	24843.05	129051.1
8.3E+09	179345.9	1.79E+14	30121.7	2105.921	28015.77	22662.58	5511.157	17151.43	107133.8
7.97E+09	169400	1.69E+14	41813.31	9112.124	32701.19	18206.16	8962.351	9243.813	80879.55
7.51E+09	165868.5	1.66E+14	62080.66	25855.17	36225.47	14389.21	10271.57	4117.645	57441.29
6.96E+09	165015.8	1.65E+14	70170.03	34933.95	35236.08	12148.58	10041.49	2107.086	48191.06
6.53E+09	127506.5	1.28E+14	12189.23	0	12189.23	32633.64	0	32633.64	109509.2
6.92E+09	140525.8	1.41E+14	14646.91	0	14646.91	40273.48	0	40273.48	119306.7
7.58E+09	155802.8	1.56E+14	11396.36	1.08E-18	11396.36	44106.95	7.28E-12	44106.95	135219.2
8.06E+09	172942	1.73E+14	12977.31	0.016411	12977.29	46954.2	1.325356	46952.87	148165.1

8.39E+09	190374.2	1.9E+14	18475.18	0.016344	18475.17	48287.18	9.159227	48278.01	156157.1
8.53E+09	203849.9	2.04E+14	22204.2	0.010623	22204.19	46717.23	25.01852	46692.2	158847.5
8.49E+09	210474.7	2.1E+14	24885.73	7.78E-10	24885.73	44522.37	77.21906	44445.15	155585.8
8.3E+09	205567.5	2.06E+14	29157.43	0	29157.44	37478.48	196.0579	37282.42	137315.2
7.97E+09	192802.1	1.93E+14	35171.66	325.1986	34846.44	28094.72	1052.072	27042.63	110902.5
7.51E+09	178457.8	1.78E+14	40532.85	2263.475	38269.36	21122.44	2217.006	18905.43	87917.8
6.96E+09	167527.3	1.68E+14	45376.43	5987.744	39388.7	15671.51	2915.952	12755.56	71619.78
6.53E+09	127506.5	1.28E+14	12189.23	0	12189.23	32633.64	0	32633.64	109509.2
6.92E+09	140525.8	1.41E+14	14646.91	0	14646.91	40273.48	0	40273.48	119306.7
7.58E+09	155872.5	1.56E+14	11418.31	0	11418.32	44139.42	0	44139.42	135266.2
8.06E+09	173548.7	1.74E+14	13686.35	0	13686.35	47379.18	0	47379.18	148106.2
8.39E+09	193462.3	1.93E+14	18991.19	0	18991.19	50182.82	0	50182.82	158948.3
8.53E+09	207845.3	2.08E+14	21670.64	0	21670.64	50124.51	0	50124.51	164078.1
8.49E+09	219041.4	2.19E+14	24600.7	0	24600.7	51326.15	0	51326.15	165890.4
8.3E+09	223149.4	2.23E+14	29450.52	0	29450.52	50600.73	0	50600.73	157242
7.97E+09	216925.3	2.17E+14	35451.79	0	35451.81	43926.92	0	43926.92	136479
7.51E+09	206976.1	2.07E+14	38445.68	0	38445.67	37935.2	0	37935.2	119650
6.96E+09	194629.4	1.95E+14	38153.77	0	38153.78	32105.33	0	32105.33	107512.9
6.5E+09	129006.5	1.29E+14	13458.9	0	13458.9	33692.53	0	33692.53	109543.4
6.87E+09	138899.8	1.39E+14	14984.18	0	14984.18	38891.42	0	38891.42	116293.4
7.61E+09	159629.8	1.6E+14	17330.57	0	17330.57	37893.64	0	37893.64	129663.4
8.26E+09	141433.7	1.41E+14	20364.18	266.1113	20098.07	9786.397	2728.336	7058.061	95372.3
8.79E+09	142332.9	1.42E+14	25135.02	1522.779	23612.24	6651.394	6156.672	494.7226	73132.28
9.17E+09	152746.8	1.53E+14	33109.47	5526.949	27582.52	10642.79	10602.23	40.55559	55450.04
9.38E+09	168209	1.68E+14	42126.98	13136.4	28990.58	8932.507	8917.507	15.00001	39760.87
9.46E+09	181052.6	1.81E+14	48952.82	27761.97	21190.85	4311.115	4302.226	8.888896	26347.24
9.41E+09	193344.9	1.93E+14	54132.54	40837.25	13295.29	1094.445	1088.89	5.55556	18950.02
9.25E+09	206819.3	2.07E+14	58930.6	44765.04	14165.57	217.5002	214.1668	3.333336	15445.57
9.03E+09	222859.1	2.23E+14	62648.11	47494.2	15153.9	13.05557	11.11112	1.944446	15462.51
6.5E+09	129017.3	1.29E+14	13458.9	0	13458.9	33694.75	0	33694.75	109554
6.87E+09	139161.8	1.39E+14	15274.46	0	15274.46	38813.09	0	38813.09	116264
7.61E+09	159448.7	1.59E+14	17797.79	0	17797.79	37556.7	17.22224	37539.47	128902.6
8.26E+09	163324.3	1.63E+14	19396.13	237.778	19158.35	23032.24	1695.557	21336.68	122542
8.79E+09	171783.7	1.72E+14	21005.29	994.1675	20011.13	13065.01	5404.449	7660.562	119432
9.17E+09	183343.2	1.83E+14	24245.57	3158.614	21086.96	15443.62	12945.84	2497.78	114314
9.38E+09	199899.6	2E+14	28588.36	9284.73	19303.63	24227.24	22893.07	1334.168	111007.3
9.46E+09	217426.6	2.17E+14	35692.81	22445.02	13247.79	35891.7	35442.25	449.4448	102071.2
9.41E+09	231093.2	2.31E+14	43533.92	33042.53	10491.4	36787.81	36782.25	5.55556	87146.46
9.25E+09	244039.4	2.44E+14	51089.49	39203.36	11886.12	31039.47	31036.14	3.333336	69799.22
9.03E+09	257848	2.58E+14	57251.71	43766.7	13485.01	24071.69	24069.74	1.944446	54516.99
6.5E+09	129017.3	1.29E+14	13458.9	0	13458.9	33694.75	0	33694.75	109554
6.87E+09	139165.4	1.39E+14	15278.35	0	15278.35	38813.09	0	38813.09	116264
7.61E+09	159607.6	1.6E+14	17420.57	0	17420.57	37706.42	15.27779	37691.14	129517.3
8.26E+09	174954.6	1.75E+14	17586.96	80.8334	17506.13	33687.25	894.7229	32792.53	139250.1
8.79E+09	187281.5	1.87E+14	18350.85	460.0004	17890.85	23715.57	3658.892	20056.68	142471.5
9.17E+09	201362.9	2.01E+14	21133.91	1780.557	19353.35	19653.63	8378.062	11275.56	144348.4
9.38E+09	214165.2	2.14E+14	24198.35	5903.894	18294.46	22847.52	14919.46	7928.062	140312.1

9.46E+09	232415.5	2.32E+14	26995.85	15224.73	11771.12	31044.19	25329.46	5714.727	139195.9
9.41E+09	252905.5	2.53E+14	31590.3	23555.57	8034.729	41338.92	39002.25	2336.669	138747.6
9.25E+09	269446	2.69E+14	38752.53	29302.52	9450.008	49179.21	48378.09	801.1118	127208.2
9.03E+09	288174.4	2.88E+14	46574.76	35548.64	11026.12	51839.76	51805.6	34.16669	115169.3
6.5E+09	129017.3	1.29E+14	13458.9	0	13458.9	33694.75	0	33694.75	109554
6.87E+09	139165.4	1.39E+14	15278.35	0	15278.35	38813.09	0	38813.09	116264.3
7.61E+09	160070.4	1.6E+14	17370.29	0	17370.29	38353.92	0	38353.92	130229.5
8.26E+09	179036.8	1.79E+14	17160.85	25.2778	17135.57	38740.03	346.1114	38393.92	144261.2
8.79E+09	196385.4	1.96E+14	17088.07	142.2223	16945.85	33484.75	1703.335	31781.41	155036.8
9.17E+09	214261.3	2.14E+14	18476.13	586.6671	17889.46	30908.64	5020.837	25887.8	163824.3
9.38E+09	229290.7	2.29E+14	20176.41	1820.557	18355.85	33399.47	11221.12	22178.35	167072.1
9.46E+09	243040.2	2.43E+14	22259.74	5184.449	17075.29	38271.98	19853.9	18418.07	165195.7
9.41E+09	260373.3	2.6E+14	24595.02	11758.9	12836.12	43565.31	29096.97	14468.34	163627.4
9.25E+09	279042.2	2.79E+14	27836.69	18777.79	9058.896	53358.38	43009.76	10348.62	157533.2
9.03E+09	305544.1	3.06E+14	32229.19	24352.52	7876.673	68722.28	63929.77	4792.504	161585.7
6.5E+09	129017	1.29E+14	13458.9	0	13458.9	33694.47	0	33694.47	109553.7
6.87E+09	139161.8	1.39E+14	15274.46	0	15274.46	38812.81	0	38812.81	116264
7.61E+09	160310.7	1.6E+14	17381.96	0	17381.96	38659.75	0	38659.75	130570.4
8.26E+09	182806.5	1.83E+14	17037.79	0	17037.79	42910.31	0	42910.31	148844.6
8.79E+09	204459.9	2.04E+14	16174.74	0	16174.74	44336.42	0	44336.42	166399.6
9.17E+09	227378.8	2.27E+14	16495.57	0	16495.57	47896.7	0	47896.7	183940.4
9.38E+09	248426	2.48E+14	17971.68	0	17971.68	55058.66	362.7781	54695.88	195511
9.46E+09	265272.4	2.65E+14	18246.96	0	18246.96	58150.05	2219.168	55930.88	202806.6
9.41E+09	284167.2	2.84E+14	17404.46	8.33334	17396.13	56418.93	7422.784	48996.15	210638.5
9.25E+09	306963.9	3.07E+14	17303.07	95.27785	17207.79	59381.16	18522.24	40858.92	221507.4
9.03E+09	328998.3	3.29E+14	19467.79	390.2781	19077.52	61118.38	30116.41	31001.97	225453
6.5E+09	129010.4	1.29E+14	13458.9	0	13458.9	33694.19	0	33694.19	109547
6.87E+09	139165.1	1.39E+14	15278.35	0	15278.35	38815.03	0	38815.03	116263.7
7.61E+09	161229.9	1.61E+14	17294.46	0	17294.46	39936.42	0	39936.42	131791.2
8.26E+09	185232.6	1.85E+14	17037.79	0	17037.79	45964.48	0	45964.48	151721
8.79E+09	208555.2	2.09E+14	16174.74	0	16174.74	50296.71	0	50296.71	171801
9.17E+09	233989.1	2.34E+14	16525.57	0	16525.57	57548.38	0	57548.38	192900.7
9.38E+09	258524.7	2.59E+14	17641.4	0	17641.4	69682.28	0	69682.28	210044.1
9.46E+09	280951.3	2.81E+14	18025.57	0	18025.57	81073.4	0	81073.4	224654.3
9.41E+09	309209.4	3.09E+14	17019.18	0	17019.18	93888.13	0	93888.13	247856.9
9.25E+09	336089.7	3.36E+14	16700.29	0	16700.29	100412.6	0	100412.6	266073.3
9.03E+09	362293.1	3.62E+14	18238.9	0	18238.9	99746.47	0	99746.47	279144.9
6.49E+09	124524	1.25E+14	12818.37	0	12818.37	32846.03	0	32846.03	105894.7
6.88E+09	135713	1.36E+14	13716.59	0	13716.59	37076	0	37076	115641.1
7.7E+09	165573	1.66E+14	16130.79	0	16130.79	45350.12	0	45350.12	141071.5
8.51E+09	185667	1.86E+14	19284.13	0	19284.13	47411.87	0	47411.87	154019.8
9.26E+09	169361.3	1.69E+14	26438.72	1276.64	25162.08	26163.3	4444.892	21718.41	124935.2
9.96E+09	181855.5	1.82E+14	38337.23	9403.869	28933.33	26968.91	13156.43	13812.48	122878
1.06E+10	193742	1.94E+14	48992.04	20289.32	28702.72	30411.02	21014.29	9396.73	121138.9
1.11E+10	196283.7	1.96E+14	64587.41	31976.89	32610.5	24195.99	16816.37	7379.617	101886.6
1.16E+10	199079.9	1.99E+14	76623.45	40594.2	36029.28	19479.65	13630.18	5849.477	85267.15
1.21E+10	203101.6	2.03E+14	87363.76	48110.9	39252.84	15511.4	10878.12	4633.281	69998.58

1.26E+10	209181.6	2.09E+14	96308.16	53968.9	42339.26	12291.34	8596.646	3694.725	57958.16
6.49E+09	124524	1.25E+14	12818.37	0	12818.37	32846.03	0	32846.03	105894.7
6.88E+09	135713	1.36E+14	13716.59	0	13716.59	37076	0	37076	115641.1
7.7E+09	165573	1.66E+14	16130.79	0	16130.79	45350.12	0	45350.12	141071.5
8.51E+09	191437.9	1.91E+14	18960.32	0	18960.32	51601.04	0	51601.04	160545.1
9.26E+09	188665.6	1.89E+14	23507.77	0	23507.77	38267.61	1954.557	36313.06	149665.8
9.96E+09	195560.6	1.96E+14	33105.28	967.8619	32137.41	35268.17	11360.81	23907.32	144541.7
1.06E+10	202362.6	2.02E+14	47124.23	10754.09	36370.14	34590.28	22065.68	12524.59	134186.2
1.11E+10	210547.6	2.11E+14	54306.49	23162.71	31143.77	34584.69	23017.07	11567.62	132748.8
1.16E+10	218324	2.18E+14	63506.97	29223.63	34283.31	34463.28	23593.07	10870.2	127886.2
1.21E+10	224937.9	2.25E+14	74046.28	36492.67	37553.61	32608.19	22686.85	9921.341	118715.5
1.26E+10	229673.5	2.3E+14	86118.29	44919.67	41198.62	28089.66	19769.27	8320.423	103916.3
6.49E+09	124524	1.25E+14	12818.37	0	12818.37	32846.03	0	32846.03	105894.7
6.88E+09	135713	1.36E+14	13716.59	0	13716.59	37076	0	37076	115641.1
7.7E+09	165573	1.66E+14	16130.79	0	16130.79	45350.12	0	45350.12	141071.5
8.51E+09	191951.8	1.92E+14	18937.9	0	18937.9	52050.32	0	52050.32	161107.4
9.26E+09	199151.6	1.99E+14	23073.66	0	23073.66	46818.15	10.00001	46808.15	161696.2
9.96E+09	208203.7	2.08E+14	31078.8	0	31078.8	45378.93	1425.557	43953.4	161449.4
1.06E+10	220011.6	2.2E+14	39885.23	0	39885.23	47825.9	2669.252	45156.65	163803
1.11E+10	226980.1	2.27E+14	50021.12	0	50021.12	44537.79	9943.23	34594.56	158761.7
1.16E+10	236029.6	2.36E+14	57836.55	1434.807	56401.74	45741.54	21087.85	24653.69	157453.1
1.21E+10	250451.3	2.5E+14	65085.64	6482.866	58602.77	51320.01	32542.28	18777.74	162192.5
1.26E+10	265332.6	2.65E+14	74770.25	13367.59	61402.69	55316.07	36210.64	19105.43	164454.7
6.49E+09	124524	1.25E+14	12818.37		12818.37	32846.03		32846.03	105894.7
6.88E+09	136034.6	1.36E+14	13717.01		13717.01	37336.89		37336.89	116045.4
7.7E+09	169330.7	1.69E+14	16105.07		16105.07	48745.98		48745.98	145494.2
8.51E+09	201343.5	2.01E+14	18875.24		18875.24	61735.99		61735.99	173592.2
9.26E+09	225965.8	2.26E+14	21668.68		21668.68	73254.61		73254.61	194610
9.96E+09	246447.1	2.46E+14	24989.85		24989.85	85183.04		85183.04	210929.1
1.06E+10	263180	2.63E+14	28704.88		28704.88	96364.27		96364.27	223479
1.11E+10	280431.1	2.8E+14	33016.92		33016.92	108906.9		108906.9	236281.1
1.16E+10	297704	2.98E+14	37370.14		37370.14	121754.5		121754.5	248912.5
1.21E+10	317093.3	3.17E+14	41596.17		41596.17	135694.5		135694.5	263805.9
1.26E+10	337567.3	3.38E+14	46719.59		46719.59	150782.3		150782.3	278826.9

6.9E+09	141284.2	1.41E+14	14313.92	0	14313.92	39794.41	0	39794.41	120328.8
7.63E+09	173532.7	1.74E+14	19400.04	256.5958	19143.44	51708.12	344.5803	51363.54	143936.1
8.26E+09	183609.4	1.84E+14	31665.72	6018.704	25647.01	32835.05	12092.38	20742.67	128154.8
8.77E+09	198757.7	1.99E+14	40305.84	13933.32	26372.51	26835.34	19610.57	7224.764	122475.9
9.15E+09	209252.8	2.09E+14	49105.29	24119.78	24985.51	24225.64	21178.37	3047.269	113118.5
9.38E+09	216301.2	2.16E+14	63089.61	37924.87	25164.75	20214.12	18659.67	1554.453	96120.87
9.47E+09	217485.1	2.17E+14	78146.04	51664.03	26482.02	13374.22	12543.4	830.8276	71826.87
9.47E+09	216523.6	2.17E+14	92835.82	64613.29	28222.53	5479.683	4992.231	487.4519	45792.85
9.4E+09	219417.4	2.19E+14	106360.7	76610.37	29750.35	1681.948	1392.352	289.5965	27599.38
9.29E+09	230036.5	2.3E+14	124492.4	93071.84	31420.6	627.5137	458.7289	168.7848	16097.24

6.9E+09	141284.2	1.41E+14	14313.92	0	14313.92	39794.41	0	39794.41	120328.8
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7.63E+09	173532.7	1.74E+14	19400.04	256.6363	19143.4	51708.12	344.8164	51363.3	143936.1
8.26E+09	194984.7	1.95E+14	27426.87	2294.815	25132.05	47370.93	4609.206	42761.73	149918.2
8.77E+09	207231.2	2.07E+14	33028.67	5514.391	27514.28	37223.19	11385.57	25837.62	145081.7
9.15E+09	212061.1	2.12E+14	38093.05	10387.56	27705.48	27099.04	17085.77	10013.27	132825.2
9.38E+09	216842	2.17E+14	46503.87	19782.02	26721.86	22640.01	18766.32	3873.688	118941.7
9.47E+09	218968.3	2.19E+14	57363.38	32411.59	24951.79	18274.28	16518.9	1755.385	100466.3
9.47E+09	218956.8	2.19E+14	71625.36	46273.4	25351.96	13521.79	12612.64	909.1496	77799.67
9.4E+09	216900.1	2.17E+14	86277.87	59719.52	26558.34	6646.813	6129.193	517.6205	52321.45
9.29E+09	218409.7	2.18E+14	99370.15	71684.5	27685.65	2104.283	1797.962	306.3215	33403.56
6.9E+09	141284.2	1.41E+14	14313.92	0	14313.92	39794.41	0	39794.41	120328.8
7.63E+09	173532.7	1.74E+14	19400.04	256.6436	19143.4	51708.12	344.8921	51363.23	143936.1
8.26E+09	200348.1	2E+14	25612.62	1525.493	24087.13	53445.12	3039.84	50405.28	159004.4
8.77E+09	216621.8	2.17E+14	30666.46	3275.875	27390.58	49044.43	6725.164	42319.27	161781
9.15E+09	220619.8	2.21E+14	34395.86	5724.17	28671.69	37335.38	11642.86	25692.52	151252.6
9.38E+09	220727.2	2.21E+14	39518.7	10634.08	28884.62	26588.62	15676.33	10912.28	134772.2
9.47E+09	219821.8	2.2E+14	45882.18	18729.28	27152.9	20020.1	16326.38	3693.719	117277
9.47E+09	220997.3	2.21E+14	48041.16	21813.12	26228.03	17452.12	14525.99	2926.133	112253.6
9.4E+09	220583.4	2.21E+14	48623.49	23674.71	24948.78	15508.67	13288.8	2219.863	107892.5
9.29E+09	218506.2	2.19E+14	52151.41	28675.8	23475.61	12326	10928.34	1397.659	97508.85
6.9E+09	141284.2	1.41E+14	14313.92	0	14313.92	39794.41	0	39794.41	120328.8
7.63E+09	173532.7	1.74E+14	19400.04	256.5135	19143.53	51708.12	344.8078	51363.31	143936.1
8.26E+09	209801.3	2.1E+14	23207.31	914.2945	22293.02	64510.97	2365.196	62145.78	172507.4
8.77E+09	232063.1	2.32E+14	26633.43	1533.464	25099.96	68737.78	4158.549	64579.23	186167.7
9.15E+09	244353	2.44E+14	29312.58	2023.798	27288.79	68446.54	5382.993	63063.55	190809.2
9.38E+09	251239	2.51E+14	32091.5	2746.17	29345.33	67511.44	6656.937	60854.5	189484.2
9.47E+09	251107	2.51E+14	33085.34	3280.176	29805.16	62209.9	7054.416	55155.49	182808.6
9.47E+09	242889.5	2.43E+14	33690.07	3964.068	29726	47626.63	7240.684	40385.94	166192.1
9.4E+09	233088.3	2.33E+14	33954.56	5088.693	28865.87	32378.78	7502.981	24875.8	147573.8
9.29E+09	223909.7	2.24E+14	34908.63	7396.419	27512.21	18350.07	7882.814	10467.26	128482.7
6.51E+09	128072.8	1.28E+14	12864.46	0	12864.46	34545.15	0	34545.15	109340.4
6.9E+09	141284.2	1.41E+14	14313.92	0	14313.92	39794.41	0	39794.41	120328.8
7.63E+09	177155.5	1.77E+14	18655.26	0	18655.26	54781.43	0	54781.43	148733
8.26E+09	213229.5	2.13E+14	23288.59	0	23288.59	69713.97	0	69713.97	176269
8.77E+09	237453.6	2.37E+14	26857.74	0	26857.74	77252.11	0	77252.11	192126.9
9.15E+09	251486	2.51E+14	29310.79	0	29310.79	79938.32	0	79938.32	199217.8
9.38E+09	260830.1	2.61E+14	31757.59	0	31757.59	83287.46	0	83287.46	201534
9.47E+09	263368.2	2.63E+14	32427.97	0	32427.97	82124.5	0	82124.5	199047.1
9.47E+09	258711.5	2.59E+14	32312.19	0	32312.19	73080.15	0	73080.15	189021.4
9.4E+09	254316.9	2.54E+14	31633.38	0	31633.38	66124.71	0	66124.71	180965.1
9.29E+09	250994.6	2.51E+14	30774.14	0	30774.14	60609.39	0	60609.39	175228.2
6.51E+09	129055.7	1.29E+14	15508.35	0	15508.35	33944.47	0	33944.47	107611.2
6.89E+09	139639	1.4E+14	16619.46	0	16619.46	37611.14	0	37611.14	116416.8
7.55E+09	172166.8	1.72E+14	18277.79	0.944445	18277.79	32888.92	1.000001	32888.92	145639
8.05E+09	177250.1	1.77E+14	16463.9	2750.836	13713.9	15450.01	1.750001	15447.23	147000.1
8.4E+09	171805.7	1.72E+14	39444.48	31805.58	7630.562	4155.559	1.777779	4152.781	99527.86

8.58E+09	198333.5	1.98E+14	86138.96	82222.29	3905.559	1030.834	1.500001	1029.445	49277.82
8.59E+09	213277.9	2.13E+14	100472.3	98416.75	2055.002	422.5003	1.055556	421.3892	18605.57
8.46E+09	239694.6	2.4E+14	108611.2	104527.9	4083.337	341.9447	0.916667	341.1114	9911.119
8.2E+09	265639.1	2.66E+14	115833.4	109250.1	6566.672	315.8336	0.88889	315.0003	5850.005
7.83E+09	286389.1	2.86E+14	117583.4	110527.9	7041.672	254.2224	0.88889	253.3335	4419.448
7.38E+09	303333.6	3.03E+14	119277.9	112083.4	7177.784	211.5002	0.88889	210.6113	3338.892
6.51E+09	129055.7	1.29E+14	15508.35	0	15508.35	33944.47	0	33944.47	107611.2
6.89E+09	139639	1.4E+14	16619.46	0	16619.46	37611.14	0	37611.14	116416.8
7.55E+09	172166.8	1.72E+14	18277.79	0.944445	18277.79	32888.92	1.000001	32888.92	145639
8.05E+09	196500.2	1.97E+14	15055.57	770.834	14286.12	16800.01	3.888892	16794.46	170500.1
8.4E+09	204583.5	2.05E+14	18763.9	9897.23	8869.452	5450.004	10.83334	5438.893	166305.7
8.58E+09	226639.1	2.27E+14	49555.6	44333.37	5211.115	1625.557	12.91668	1612.501	138916.8
8.59E+09	245528	2.46E+14	86805.63	83916.73	2897.225	976.6674	11.50001	965.2786	93916.74
8.46E+09	259889.1	2.6E+14	102416.7	100611.2	1805.279	841.3896	8.666674	832.7784	61000.05
8.2E+09	275805.8	2.76E+14	112777.9	110194.5	2571.669	835.5562	4.111114	831.3896	33972.25
7.83E+09	296111.3	2.96E+14	123805.7	113972.3	9830.563	795.834	1.111112	794.4451	14386.12
7.38E+09	316944.7	3.17E+14	132500.1	115889	16616.68	731.1117	0.88889	730.2784	7733.34
6.51E+09	129055.7	1.29E+14	15508.35	0	15508.35	33944.47	0	33944.47	107611.2
6.89E+09	139639	1.4E+14	16619.46	0	16619.46	37611.14	0	37611.14	116416.8
7.55E+09	172166.8	1.72E+14	18277.79	0.944445	18277.79	32888.92	1.000001	32888.92	145639
8.05E+09	200444.6	2E+14	15013.9	253.4446	14761.12	20536.13	242.9446	20291.68	175444.6
8.4E+09	217222.4	2.17E+14	12616.68	2875.002	9741.674	11405.56	2394.724	9011.118	190166.8
8.58E+09	241361.3	2.41E+14	18805.57	12516.68	6286.116	12350.01	8580.562	3769.447	196972.4
8.59E+09	261944.7	2.62E+14	39361.14	35527.81	3833.336	14155.57	12375.01	1779.724	177305.7
8.46E+09	273750.2	2.74E+14	63694.5	61416.72	2270.557	12263.9	11013.9	1250.001	136639
8.2E+09	286666.9	2.87E+14	88166.74	86666.74	1486.946	8280.562	7175.006	1107.223	89944.52
7.83E+09	301111.4	3.01E+14	110250.1	108972.3	1274.168	3408.336	2145.279	1263.612	48277.82
7.38E+09	313889.1	3.14E+14	116694.5	115527.9	1155.556	1499.723	136.9446	1362.779	31361.14
6.51E+09	129055.7	1.29E+14	15508.35	0	15508.35	33944.47	0	33944.47	107611.2
6.89E+09	139639	1.4E+14	16619.46	0	16619.46	37611.14	0	37611.14	116416.8
7.55E+09	172166.8	1.72E+14	18277.79	0.944445	18277.79	32888.92	1.000001	32888.92	145639
8.05E+09	202055.7	2.02E+14	15580.57	219.6668	15361.12	22016.68	458.6115	21558.35	176639
8.4E+09	223694.6	2.24E+14	13608.34	2401.669	11205.56	16736.12	4675.004	12061.12	196472.4
8.58E+09	255722.4	2.56E+14	18838.9	10241.67	8597.229	24277.8	18086.13	6188.894	214472.4
8.59E+09	284722.5	2.85E+14	32555.58	26050.02	6505.561	35055.58	32027.8	3033.336	214722.4
8.46E+09	301666.9	3.02E+14	46138.93	41472.26	4661.115	38944.48	36888.92	2056.391	197555.7
8.2E+09	317222.5	3.17E+14	56027.82	52694.49	3347.225	36055.58	34250.03	1818.613	177000.1
7.83E+09	325000.3	3.25E+14	64250.05	61888.94	2360.002	30583.36	28777.8	1803.613	150222.3
7.38E+09	338889.2	3.39E+14	66055.61	64333.38	1727.224	29833.36	28055.58	1796.946	145250.1
6.51E+09	129055.7	1.29E+14	15508.35	0	15508.35	33944.47	0	33944.47	107611.2
6.89E+09	139639	1.4E+14	16619.46	0	16619.46	37611.14	0	37611.14	116416.8
7.55E+09	172166.8	1.72E+14	18277.79	0.944445	18277.79	32888.92	1.000001	32888.92	145639
8.05E+09	209639.1	2.1E+14	15355.57	38.05559	15316.68	29250.02	486.3893	28750.02	185194.6
8.4E+09	243916.9	2.44E+14	12883.34	355.8336	12527.79	32111.14	5961.116	26158.35	220583.5
8.58E+09	285000.2	2.85E+14	13405.57	1411.112	11994.45	49972.26	28555.58	21419.46	256778
8.59E+09	325000.3	3.25E+14	15227.79	3302.78	11927.79	78972.29	63722.27	15255.57	285000.2
8.46E+09	345833.6	3.46E+14	17188.9	5861.116	11327.79	90666.74	81694.51	8969.452	286944.7

8.2E+09	354444.7	3.54E+14	19013.9	9150.007	9863.897	85277.85	80666.73	4588.893	270944.7
7.83E+09	355555.8	3.56E+14	21791.68	13538.9	8252.784	78861.17	76305.62	2569.447	244916.9
7.38E+09	365555.8	3.66E+14	25975.02	18127.79	7850.006	78055.62	75333.39	2739.169	231528
6.51E+09	129055.7	1.29E+14	15508.35	0	15508.35	33944.47	0	33944.47	107611.2
6.89E+09	139639	1.4E+14	16619.46	0	16619.46	37611.14	0	37611.14	116416.8
7.55E+09	174111.3	1.74E+14	18319.46	0	18319.46	38027.81	0	38027.81	147666.8
8.05E+09	219333.5	2.19E+14	15366.68	0	15366.68	45500.04	0	45500.04	195889
8.4E+09	270972.4	2.71E+14	12797.23	0	12797.23	64888.94	0	64888.94	250833.5
8.58E+09	325000.3	3.25E+14	13258.34	0	13258.34	98166.75	0	98166.75	303889.1
8.59E+09	384444.8	3.84E+14	14736.12	0	14736.12	147583.5	0	147583.5	359444.7
8.46E+09	437778.1	4.38E+14	16127.79	0	16127.79	195527.9	0	195527.9	406667
8.2E+09	482222.6	4.82E+14	17513.9	0	17513.9	230416.9	0	230416.9	440278.1
7.83E+09	498611.5	4.99E+14	19136.13	0	19136.13	243555.8	0	243555.8	439167
7.38E+09	506667.1	5.07E+14	20805.57	0	20805.57	246722.4	0	246722.4	425000.3

Primary energy (fossil, CCS)	Primary energy (fossil, no CCS)	Primary energy (gas)	Primary energy (gas, CCS)	Primary energy (geothermal)	Primary energy (hydro)	Primary energy (no CCS)	Primary energy (renewables excl. bio)	Primary energy (nuclear)	Primary energy (oil)
0	109509.2	28318.22	0		2931.677	28318.22	3098.927	2767.954	48557.37
0	119306.7	31332.39	0		3440.925	31332.39	3884.651	2756.29	47700.82
571.515	112634.6	35654.67	390.6875		4400.892	35264	6275.659	2853.655	43024.23
6935.883	72192.72	38605.11	5695.963		4935.918	32909.14	7578.488	3003.408	24053.38
23604.51	37969.27	41181.2	20185.81		5947.516	20995.39	18310.6	2227.568	12110.34
31148.43	25944.19	40893.76	26315.95		5483.807	14577.81	27915.25	1016.863	9357.499
33926.87	21034.34	40089.17	28246.49		5231.179	11842.67	33147.52	871.7987	7941.329
36837.4	17186.77	39527.67	30525.11		5738.335	9002.54	35662.13	960.1889	7166.192
30213.82	14442.84	31751.8	24530.01		6130.361	7221.795	39272.95	1182.995	6447.264
21301.26	12289.35	22818.14	17037.39		6194.5	5780.746	41828.41	1464.955	5895.558
13870.53	11412.43	16546.96	11131.09		6056.463	5415.868	40514.62	1359.365	5480.043
0	109509.2	28318.22	0		2931.677	28318.22	3098.927	2767.954	48557.37
0	119306.7	31332.36	0		3440.925	31332.36	3884.651	2756.29	47700.82
3.00E-09	131123.7	41295.31	1.58E-10		4556.901	41295.31	6324.403	2919.105	47542.43
1868.808	127913.1	51555.68	526.5546		5383.296	51029.13	9816.821	3060.619	41445.67
10140.78	106700.3	55996.1	4166.65		5999.935	51829.46	16883.14	2363.34	33893.08
14747.57	87925.35	53562.71	6182.03		6230.208	47380.68	26843.84	1084.737	30571.08
18815.68	72125.69	48288.79	7021.245		6429.991	41267.53	35140.68	785.5809	27637.6
19912.68	56732.77	38979.75	7482.451		6325.502	31497.3	40427.96	588.911	23297.99
19939.08	39848.65	32049.5	8872.154		6301.908	23177.35	42897.89	571.7749	15160.14
19093.7	30879.86	27997.83	9058.038		6765.514	18939.79	42369.18	689.0964	10714.16
16956.13	29671.06	28045.08	9517.127		6961.117	18527.94	47834.12	701.5105	10243.78
0	109509.2	28318.22	0		2931.677	28318.22	3098.927	2767.954	48557.37
0	119306.7	31332.36	0		3440.925	31332.36	3884.651	2756.29	47700.82
8.37E-12	135275.6	42589.37	4.41E-13		4598.673	42589.37	6361.318	2934.539	48639.93
2.538443	144790.4	55891.13	0.061438		5385.526	55891.07	9245.662	2999.972	44002.26
57.25755	144169.5	65486.11	4.13357		6049.594	65481.97	15119.81	2177.351	38148.14
615.9832	137342.8	68529.97	86.07193		6255.683	68443.92	25088.23	947.3177	36473.22
3056.676	125994.4	67958.83	685.5295		6488.066	67273.3	34040.48	619.5147	33879.11
8442.032	98691.8	55771.88	2928.716		6624.78	52843.15	42751.75	376.1914	28699.36
13363.46	67516.08	42743.84	4398.876		6678.28	38344.95	47652.62	236.2891	19929.55
15527.31	41914	30950.52	5251.743		6875.217	25698.8	47418.25	278.8533	12101.56
14694.42	33496.64	26678.17	4648.359		7019.072	22029.8	47877.7	335	9364.316
0	109509.2	28318.22	0		2931.677	28318.22	3098.927	2767.954	48557.37
0	119306.7	31332.36	0		3440.925	31332.36	3884.651	2756.29	47700.82
7.68E-12	135219.2	42507.67	4.04E-13		4598.912	42507.67	6360.015	2935.636	48604.62
1.386774	148163.8	56838.91	0.045007		5386.782	56838.85	9094.41	2991.8	44372.04

9.92956	156147.2	68494.2	0.753972	6051.113	68493.44	14175.72	2134.499	39375.7
26.12075	158821.4	73486.5	1.09152	6272.705	73485.42	22722.56	882.8207	38643.78
78.40413	155507.4	74419.59	1.18455	6497.588	74418.42	30461.77	528.5068	36643.84
197.6974	137117.5	67887.83	1.638347	6706.489	67886.19	39963.88	264.2906	31948.91
1695.452	109207	59156.41	643.3452	6833.006	58513.08	47904.96	95.19405	23651.38
3936.851	83980.94	50154.01	1714.132	6969.508	48439.87	51298.89	122.8914	16641.35
5311.243	66308.53	43509.04	2390.417	7163.386	41118.62	51954.24	135.8148	12439.23
0	109509.2	28318.22	0	2931.677	28318.22	3098.927	2767.954	48557.37
0	119306.7	31332.36	0	3440.925	31332.36	3884.651	2756.29	47700.82
0	135266.2	42489.37	0	4599.779	42489.37	6360.217	2936.33	48637.37
0	148106.2	56390.05	0	5386.874	56390.05	9051.183	2991.614	44336.95
0	158948.3	69147.58	0	6051.11	69147.58	13965.58	2125.479	39617.92
0	164078.1	74683.06	0	6276.297	74683.06	22045.46	869.3021	39270.56
0	165890.4	76821.54	0	6496.944	76821.54	29043.49	509.669	37742.73
0	157242	72854.59	0	6720.491	72854.59	37396.36	236.7996	33786.67
0	136479	66613.17	0	6871.064	66613.17	46286.1	57.27229	25938.95
0	119650	62399.55	0	7030.225	62399.55	50319.66	51.59282	19315.21
0	107512.9	60344.44	0	7301.445	60344.44	50564.1	35.60531	15063.13
0	109543.4	27911.69	0	99.44452	2946.113	27911.69	3237.503	2768.336
0	116293.4	29323.63	0	151.9446	3576.392	29323.63	4876.948	2749.169
0	129663.4	33891.14	0	168.889	4267.781	33891.14	9184.73	3453.058
6235.283	89137.02	38870.31	3506.947	365.8336	5970.005	35363.36	20250.85	5455.004
20047.52	53084.76	38767.25	13890.84	950.2785	7799.451	24876.41	34992.25	9094.174
25348.63	30101.41	35501.14	14746.4	1472.779	8609.729	20754.74	47695.04	16512.79
18163.63	21597.24	26995.02	9246.119	2060.002	9399.452	17748.9	59260.33	27138.08
8315.284	18031.96	19141.4	4013.059	2512.502	9977.508	15128.35	73071.73	32922.8
2209.446	16740.57	15645.29	1120.556	2736.947	10242.79	14524.73	86578.4	34019.19
215.278	15230.29	13906.96	1.111112	2933.336	10421.4	13905.84	102266.2	30530.58
11.66668	15450.85	14658.62	0.555556	3171.114	10539.18	14658.07	123195.1	22081.96
0	109554	27905.02	0	99.44452	2945.558	27905.02	3238.058	2768.336
0	116264	29362.52	0	151.9446	3575.558	29362.52	4877.504	2749.169
55.83338	128846.8	33747.53	38.61114	168.889	4267.226	33708.92	9243.063	3507.503
3930.003	118612	42463.65	2234.446	153.0557	5359.171	40229.2	16335.29	5055.282
15334.46	104097.6	53162.26	9930.008	148.3335	6021.949	43232.26	24062.8	7297.228
38354.48	75959.51	59637.27	25408.63	227.2224	7393.061	34228.64	32752.25	12043.62
51710.87	59296.44	60230.33	28817.8	342.5003	8125.007	31412.53	41453.92	18872.24
57751.99	44319.2	54712.54	22309.74	573.3338	9145.285	32402.8	53331.99	26361.97
51654.21	35492.25	46636.43	14871.96	1146.668	9863.619	31764.47	69556.17	30903.64
39316.14	30483.08	37301.42	8280.007	1759.724	10396.4	29021.41	90428.96	32801.97
26465.3	28051.69	29781.97	2395.557	2383.057	10535.29	27386.41	115114.3	31032.25
0	109554	27905.02	0	99.44452	2945.558	27905.02	3238.058	2768.336
0	116264	29362.52	0	151.9446	3575.558	29362.52	4877.504	2749.169
35.83336	129481.5	34141.69	20.55557	168.889	4244.17	34121.14	9164.73	3507.503
915.2785	138334.8	43725.59	20.55557	151.389	4766.115	43705.03	14507.23	3617.781
4339.726	138131.8	56243.38	680.8339	38.61114	5940.283	55562.54	22214.74	4255.281
11460.01	132888.4	67445.05	3081.947	89.72229	6376.672	64363.11	29388.63	6503.894
26822.8	113489.3	72843.11	11903.34	159.4446	7497.784	60939.77	37856.97	11818.62

51588.37	87607.57	73712.84	26258.91	241.6669	8322.784	47453.93	45204.76	21044.18	34438.92
67052	71695.61	76085.06	28049.74	415.0003	9012.785	48035.32	53647.54	28958.63	21323.63
70252.83	56955.32	67665.61	21874.74	720.5561	9917.508	45790.87	69633.67	33916.14	10363.34
66455.61	48713.65	58182.82	14650.01	1280.001	10352.51	43532.81	89136.74	37405.59	5146.671
0	109554	27905.02	0	99.44452	2945.558	27905.02	3238.058	2768.336	47954.21
0	116264.3	29362.8	0	151.9446	3575.558	29362.8	4877.504	2749.169	48088.37
0	130229.5	34211.97	0	168.889	4244.17	34211.97	8965.841	3507.225	57663.66
346.1114	143915.1	43577.26	0	148.889	4696.393	43577.26	14226.96	3394.725	61943.94
1703.335	153333.5	56675.05	0	36.11114	5748.893	56675.05	21045.85	3226.391	64877
5020.837	158803.5	68732	0	36.11114	6057.227	68732	27331.69	4641.948	64183.66
11390.56	155681.5	78478.95	169.4446	33.61114	6434.45	78309.51	34641.69	7412.506	55193.66
21178.35	144017.3	84290.07	1324.446	23.61113	7122.228	82965.62	41813.64	13790.57	42633.65
36531.97	127095.4	87881.74	7435.006	47.22226	8229.173	80446.73	48296.71	23896.96	32180.3
61373.38	96159.8	82461.73	18363.63	187.2224	9525.285	64098.11	57386.71	36337.53	21713.07
83489.23	78096.45	78515.34	19559.46	391.3892	9910.563	58955.88	68963.94	42823.37	14348.07
0	109553.7	27905.02	0	99.44452	2945.558	27905.02	3238.058	2768.336	47954.21
0	116264	29362.8	0	151.9446	3575.281	29362.8	4877.226	2749.169	48088.37
0	130570.4	34171.69	0	168.889	4180.837	34171.69	8867.229	3493.058	57738.94
0	148844.6	43297.26	0	143.889	4639.448	43297.26	13785.57	3146.114	62636.99
0	166399.6	56030.6	0	33.05558	5650.838	56030.6	19746.13	2152.502	66032.55
0	183940.4	68872.28	0	33.05558	5863.06	68872.28	25204.74	1750.557	67171.44
362.7781	195148.2	79365.06	0	31.11114	6127.505	79365.06	31990.86	2965.002	61087.27
2219.168	200587.4	89307.02	0	10.00001	6480.839	89307.02	38855.03	5381.949	55349.49
7422.784	203215.7	93322.02	0	13.8889	6741.672	93322.02	45566.7	10580.29	60897.55
18522.24	202985.2	94396.46	0	14.16668	7040.561	94396.46	52078.93	16098.9	67729.78
30116.41	195336.5	92480.35	0	14.72223	9180.285	92480.35	58406.16	25728.08	71854.22
0	109547	27905.02	0	99.44452	2945.28	27905.02	3237.78	2768.336	47947.82
0	116263.7	29359.75	0	151.9446	3575.281	29359.75	4877.226	2749.169	48088.93
0	131791.2	34281.97	0	168.889	4243.892	34281.97	8828.896	3317.225	57572.82
0	151721	43045.87	0	142.5001	4695.004	43045.87	13385.29	3096.114	62710.61
0	171801	54643.38	0	29.72225	5274.171	54643.38	18578.9	2014.724	66860.89
0	192900.7	66994.5	0	29.72225	5425.56	66994.5	23378.07	1198.612	68357.83
0	210044.1	77236.17	0	29.72225	5646.949	77236.17	29281.69	1570.001	63125.61
0	224654.3	85796.18	0	9.166674	6151.394	85796.18	35552.53	2737.502	57784.77
0	247856.9	89318.4	0	9.166674	6599.728	89318.4	39530.59	4827.504	64650.33
0	266073.3	90644.24	0	9.166674	6855.005	90644.24	44973.65	8362.229	75016.45
0	279144.9	96451.47	0	2.77778	6925.283	96451.47	52334.49	12592.79	82947.01
0	105894.7	27423.24	0	57.47227	2895.725	27423.24	3067.836	2743.086	45625.45
0	115641.1	29617.16	0	59.86116	3318.447	29617.16	3539.003	2816.28	48948.01
0	141071.5	36421.31	0	70.61117	4266.253	36421.31	4713.837	3656.808	59300.08
0	154019.8	42766.37	0	81.47229	5254.754	42766.37	6899.422	5463.643	63841.58
11614.73	113320.5	38722.56	4330.642	93.4723	7106.811	34391.89	11708.81	6278.533	60049.41
35108.69	87769.29	38623.5	12413.93	103.6112	7559.034	26209.58	15210.85	5429.393	57285.6
52559.46	68579.5	38312.98	17592.68	112.5556	7829.673	20720.29	19164.88	4446.115	52414.96
45702.65	56183.93	33424.53	15761.73	121.3334	8562.951	17662.79	25471.3	4338.42	44266.09
39679.14	45588.01	28865.11	14049.37	129.639	8831.646	14815.73	32772.97	4416.365	36922.39
33225.08	36773.5	24156.66	11917.93	137.889	8831.646	12238.7	41336.87	4402.309	30330.52

27564.72	30393.44	20368.32	10074.12	146.7501	8831.646	10294.2	50654.32	4260.976	25298.49
0	105894.7	27423.24	0	57.47227	2895.725	27423.24	3067.836	2743.086	45625.45
0	115641.1	29617.16	0	59.86116	3318.447	29617.16	3539.003	2816.28	48948.01
0	141071.5	36421.31	0	70.61117	4266.253	36421.31	4713.837	3656.808	59300.08
0	160545.1	42974.62	0	80.13895	5252.199	42974.62	6468.811	5463.643	65969.44
1954.557	147711.3	44420.92	0	90.13896	6609.894	44420.92	9345.702	6146.283	66977.28
16713.35	127828.4	44750.42	3952.031	100.0834	7350.728	40798.42	12145.43	5768.227	64523.11
37261.86	96924.27	42187.2	10201.59	108.9445	7861.84	31985.61	15779.48	5272.782	57408.71
48713.46	84035.35	43484.2	15962.15	117.6668	8232.368	27522.05	18842.88	4649.448	54679.9
54089.9	73796.31	42965.01	18268.82	126.0279	8496.59	24696.19	22622.27	4308.531	50457.93
52235.88	66479.58	40614.62	17735.15	134.3057	8710.563	22879.46	28021.77	4154.392	45492.65
47182.57	56733.77	36236.92	16287.46	143.2223	8831.646	19949.46	35355.36	4283.531	39589.73
0	105894.7	27423.24	0	57.47227	2895.725	27423.24	3067.836	2743.086	45625.45
0	115641.1	29617.16	0	59.86116	3318.447	29617.16	3539.003	2816.28	48948.01
0	141071.5	36421.31	0	70.61117	4266.253	36421.31	4713.837	3656.808	59300.08
0	161107.4	42949.62	0	79.77784	5252.032	42949.62	6442.866	5463.643	66107.44
10.00001	161686.2	46300.68	0	88.50007	6212.366	46300.68	8560.785	5820.949	68577.36
1425.557	160023.9	48751.73	0	97.55563	6937.561	48751.73	10676.95	4998.615	67318.75
2669.252	161133.8	51902.62	0	106.2501	7138.589	51902.62	12316.73	4006.614	64074.55
10789.76	147972	53039.82	628.0838	114.9168	7653.562	52411.74	14584.65	3612.614	61184.13
26165.24	131287.9	53762.15	3735.253	123.2779	7999.118	50026.9	17369.13	3370.892	57949.41
39802.7	122389.9	55262.63	5296.81	131.6112	8180.757	49965.82	20158.85	3014.225	55609.91
47474.15	116980.5	56505.6	8145.673	140.5834	8250.951	48359.93	23340.13	2767.53	52632.99
	105894.7	27423.24		57.47227	2895.725	27423.24	3067.836	2743.086	45625.45
	116045.4	29646.97		59.86116	3285.558	29646.97	3506.281	2765.863	49061.57
	145494.2	36493.72		71.47228	4064.031	36493.72	4353.781	3377.697	60254.49
	173592.2	44424.73		83.02784	4611.67	44424.73	4996.476	3879.586	67431.47
	194610	50597.21		94.33341	5355.893	50597.21	5857.838	3829.364	70758.14
	210929.1	56330.55		104.639	6515.283	56330.55	7142.061	3386.114	69415.5
	223479	61082.74		113.9445	7276.45	61082.74	8085.034	2911.002	66032.03
	236281.1	63799.02		123.0834	7567.589	63799.02	8588.59	2544.558	63575.13
	248912.5	66160.05		131.889	7839.09	66160.05	9172.868	2248.446	60997.97
	263805.9	68548.03		140.6946	8000.423	68548.03	9693.98	1997.252	59563.41
	278826.9	71143.83		150.1946	8046.701	71143.83	10192.06	1828.779	56900.82
0	120328.8	31623.58	0	68.09047	3441.928	31623.58	3885.209	2756.29	48910.83
707.2135	143228.9	39496.05	318.3804	469.7754	3616.626	39177.67	6168.852	4027.688	52731.9
17467.37	110687.4	45423.1	5034.82	1167.688	3795.765	40388.29	11726.16	12062.67	49896.65
30095.63	92380.31	48688.41	10023.66	1430.434	4058.205	38664.74	16951.54	19024.35	46952.2
35752.72	77365.74	46895.17	14035.87	1565.785	4403.956	32859.3	22163.32	24865.73	41997.65
35085.53	61035.34	43717.26	15946.6	1621.388	4749.599	27770.66	26302.74	30787.95	32189.48
27235.31	44591.56	35304.06	14290	1639.748	5094.836	21014.05	31341.02	36171.18	23148.58
15453.12	30339.73	25574.63	10137.06	1623.497	5441.199	15437.57	37026.74	40868.16	14738.53
7390.593	20208.78	17628.61	5786.589	1612.51	5786.946	11842.02	45173.37	40283.9	8288.816
2531.206	13566.04	11678.64	1988.198	1265.839	5959.822	9690.443	50866.17	38580.64	3791.088
0	120328.8	31623.58	0	68.09053	3441.928	31623.58	3885.209	2756.29	48910.83

707.4046	143228.7	39496.05	318.339	469.7754	3616.626	39177.71	6168.852	4027.688	52731.9
6888.525	143029.7	49954.42	2137.936	978.2611	3795.765	47816.48	9686.158	7953.476	52592.9
16499.1	128582.6	56089.66	4893.762	1282.377	4058.205	51195.89	14564.38	14556.43	51768.85
25720.32	107104.9	56176.43	8306.871	1456.892	4403.956	47869.56	19841.83	21301.06	49549.71
30700.9	88240.77	53248.76	11488.68	1546.93	4749.703	41760.09	24850.26	26546.2	43052.89
29472.94	70993.38	45832.1	12514.56	1561.718	5095.296	33317.53	29411.76	31726.84	36359.94
24691.28	53108.4	36926.21	11674.69	1521.411	5441.199	25251.52	33729.41	35802.4	27351.68
15379.66	36941.79	27570.14	8908.558	1477.904	5786.946	18661.58	40148.88	38151.89	18104.5
7557.5	25846.06	19658.02	5523.465	1398.719	5959.822	14134.56	47834.02	37802	11641.25

0	120328.8	31623.58	0	68.09053	3441.928	31623.58	3885.209	2756.29	48910.83
707.4499	143228.6	39496.05	318.3324	469.7754	3616.626	39177.72	6168.852	4027.688	52731.9
4557.867	154446.6	52105.7	1426.535	899.1416	3795.765	50679.16	9002.652	6728.393	53453.63
9801.421	151979.6	59348.6	2948.687	1157.488	4058.205	56399.91	12882.94	11291.36	53388
16850.89	134401.7	61396.45	5023.456	1337.083	4403.956	56372.99	17606.35	17365.04	52520.76
23681.33	111090.8	59669.5	7687.301	1475.188	4749.703	51982.2	23200.4	23235.91	48514.06
26264.24	91012.81	52649.51	9544.393	1522.486	5095.449	43105.12	28294.21	28368.33	44607.43
24203.66	88049.96	50794.26	9431.401	1391.703	5415.435	41362.86	30148.63	30553.85	44007.24
22570.91	85321.62	48953.51	9008.773	1273.387	5786.946	39944.74	32335.9	31731.46	43430.36
19361.89	78146.96	45252.47	8148.824	1204.465	5959.822	37103.65	36910.03	31935.89	39930.38

0	120328.8	31623.58	0	68.09053	3441.928	31623.58	3885.209	2756.29	48910.83
706.8287	143229.2	39496.05	318.0114	469.7754	3616.626	39178.04	6168.852	4027.688	52731.9
3273.608	169233.8	54349.48	858.5529	810.7903	3795.765	53490.93	8351.13	5735.447	53646.93
5585.957	180581.7	63197.94	1377.078	990.6374	4058.205	61820.86	11042.94	8219.01	54231.97
7233.215	183576	67461.09	1800.983	1057.927	4403.956	65660.11	13506.28	10724.9	54901.57
8921.723	180562.5	68039.08	2199.221	1101.617	4749.703	65839.86	16593.68	13069.57	53933.7
9314.527	173494.1	64743.65	2188.979	1129.148	5095.449	62554.67	19648.48	15564.6	55855.04
9757.382	156434.7	61582.88	2422.557	1203.616	5441.199	59160.32	24149.91	18857.5	56982.55
10540.88	137032.9	58840.44	2909.856	1224.087	5786.946	55930.58	29450.69	22109.21	56354.59
11837.55	116645.2	56529.85	3791.828	1192.915	5959.822	52738.03	35677.9	24840.48	53602.78

0	109340.4	27445.5	0	58.20096	2933.274	27445.5	3099.994	2767.953	47349.72
0	120328.8	31623.58	0	68.09053	3441.928	31623.58	3885.209	2756.29	48910.83
0	148733	40819.51	0	453.3049	3616.626	40819.51	5968.163	3799.105	53132.06
0	176269	54173.87	0	787.0885	3795.765	54173.87	8166.085	5505.814	52381.21
0	192126.9	62810.18	0	956.7709	4058.205	62810.18	10702.96	7765.958	52064.62
0	199217.8	67041.43	0	1012.887	4403.956	67041.43	13009.09	9948.332	52238.01
0	201534	67567.5	0	1039.765	4749.703	67567.5	15647.65	11890.85	50679.03
0	199047.1	64174.89	0	1034.629	5095.449	64174.89	18092	13801.12	52747.69
0	189021.4	61181.33	0	1063.596	5441.199	61181.33	21361.13	16016.76	54759.92
0	180965.1	58973.56	0	1045.101	5786.946	58973.56	24441.55	17276.88	55866.81
0	175228.2	58411.9	0	992.6888	5959.822	58411.9	27340.7	17651.61	56206.87
0	107611.2	27244.47	0	60.91672	2969.447	27244.47	3138.891	2811.113	46444.48
0	116416.8	31166.69	0	91.05563	3144.447	31166.69	3786.114	2830.558	47638.93
2.166668	145639	47083.37	1.194445	112.8334	2988.891	47083.37	4888.893	3377.78	65666.72
531.1115	146472.3	42722.26	529.1671	366.1114	3686.114	42194.48	7961.117	5822.227	88833.4
2947.225	96583.41	26380.58	2944.447	1448.612	7633.339	23436.13	21419.46	11402.79	69000.06

3572.225	45722.26	16077.79	3569.447	4402.781	10950.01	12508.34	46833.37	16086.12	32166.69
3575.003	15030.57	10050.01	3575.003	7825.006	12011.12	6477.783	75555.62	18630.57	8133.34
2441.669	7469.45	5825.005	2440.558	10741.68	12402.79	3383.336	101194.5	19997.24	3744.447
832.2229	5019.448	2505.28	831.3896	12180.57	12733.34	1673.89	124277.9	19683.35	3030.558
331.6669	4088.892	1533.89	330.8336	12500.01	13027.79	1203.057	145805.7	18658.35	2632.224
38.4167	3300.003	718.3339	37.52781	12775.01	13230.57	680.8339	163222.4	17413.9	2409.169
0	107611.2	27244.47	0	60.91672	2969.447	27244.47	3138.891	2811.113	46444.48
0	116416.8	31166.69	0	91.05563	3144.447	31166.69	3786.114	2830.558	47638.93
2.166668	145639	47083.37	1.194445	112.8334	2988.891	47083.37	4888.893	3377.78	65666.72
1208.612	169277.9	60916.72	1204.723	231.1946	3169.447	59722.27	6172.227	4775.004	92777.85
11869.45	154416.8	65583.39	11858.34	465.8337	4994.448	53750.04	11402.79	8122.229	95250.08
23222.24	115694.5	61416.72	23208.35	1371.112	8391.673	38222.25	24925.02	13272.23	75861.17
25144.46	68777.83	50777.82	25133.35	3827.781	10758.34	25638.91	47277.82	17527.79	42166.7
21161.13	39833.37	41388.92	21152.79	7472.228	11980.57	20250.02	76222.28	20250.02	18763.9
11100.01	22863.91	25450.02	11094.45	11013.9	12336.12	14352.79	107916.8	21152.79	7677.784
4575.004	9811.119	10522.23	4575.004	13886.12	12513.9	5947.227	138305.7	19611.13	3069.447
2344.169	5388.893	4494.448	2343.335	15241.68	12663.9	2150.557	159166.8	17522.24	2509.446
0	107611.2	27244.47	0	60.91672	2969.447	27244.47	3138.891	2811.113	46444.48
0	116416.8	31166.69	0	91.05563	3144.447	31166.69	3786.114	2830.558	47638.93
2.166668	145639	47083.37	1.194445	112.8334	2988.891	47083.37	4888.893	3377.78	65666.72
1113.89	174333.5	66666.72	870.834	213.7779	3002.78	65805.61	5652.782	4313.892	88250.07
12455.57	177694.6	83250.07	10061.12	331.6669	4027.781	73194.5	8263.896	6180.561	95500.08
42388.92	154555.7	92972.3	33805.58	752.2228	6533.339	59166.71	16086.12	9500.008	91638.96
56250.05	121027.9	90611.18	43888.92	2099.724	9261.119	46722.26	31833.36	13455.57	72527.84
51555.6	85083.4	79777.84	40527.81	4788.893	10994.45	39222.25	56138.93	17266.68	44611.15
34222.25	55694.49	57027.82	27061.13	8150.007	12008.34	29972.25	88388.96	20238.91	24636.13
14302.79	33972.25	31305.58	12155.57	12166.68	12319.45	19155.57	122027.9	20563.91	13547.23
7188.895	24172.24	20338.91	7050.006	15408.35	12452.79	13288.9	147416.8	18538.9	9519.452
0	107611.2	27244.47	0	60.91672	2969.447	27244.47	3138.891	2811.113	46444.48
0	116416.8	31166.69	0	91.05563	3144.447	31166.69	3786.114	2830.558	47638.93
2.166668	145639	47083.37	1.194445	112.8334	2988.891	47083.37	4888.893	3377.78	65666.72
947.7785	175694.6	66555.61	489.1671	210.0002	2972.225	66083.39	5600.004	4250.003	88055.63
9838.897	186639	84222.29	5163.893	291.9447	3830.559	79055.62	7669.451	5947.227	95500.08
37777.81	176694.6	96000.08	19694.46	449.4448	5980.56	76305.62	13261.12	9158.341	94194.52
65027.83	149666.8	97750.08	33000.03	981.9452	8550.007	64750.05	24288.91	13172.23	81888.95
72694.5	124861.2	97611.19	35805.58	2158.057	10105.56	61805.61	41444.48	16402.79	60972.27
66750.05	110250.1	90722.29	32500.03	3927.781	11272.23	58222.27	65555.61	18602.79	50194.48
56611.16	93611.19	76222.28	27833.36	6386.116	11938.9	48388.93	91694.52	18944.46	43416.7
53222.26	92027.85	74000.06	25180.58	8105.562	12197.23	48805.59	110111.2	17461.13	41416.7
0	107611.2	27244.47	0	60.91672	2969.447	27244.47	3138.891	2811.113	46444.48
0	116416.8	31166.69	0	91.05563	3144.447	31166.69	3786.114	2830.558	47638.93
2.166668	145639	47083.37	1.194445	112.8334	2988.891	47083.37	4888.893	3377.78	65666.72
516.3893	184666.8	67472.28	29.94447	193.4446	2844.447	67444.5	5272.226	3825.003	88472.29
6222.227	214361.3	90944.52	261.5835	256.2502	3150.003	90694.52	6016.671	4433.337	97500.08
29944.47	226833.5	108583.4	1389.446	299.1669	4483.337	107194.5	8744.451	6172.227	98250.08
68583.39	216416.8	115666.8	4866.671	323.3336	6833.339	110777.9	14952.79	9786.119	90361.18
91500.07	195416.8	118861.2	9816.675	376.1114	8766.674	109027.9	26488.91	15261.12	77416.73

94166.74	176777.9	112416.8	13491.68	602.2227	10088.9	98916.75	43638.92	20830.57	73250.06
89888.96	155027.9	100277.9	13577.79	1272.779	11275.01	86694.51	66055.61	22838.91	65777.83
85361.18	146139	95527.85	10044.45	2094.446	12183.34	85500.07	86805.63	21111.13	57916.71
0	107611.2	27244.47	0	60.91672	2969.447	27244.47	3138.891	2811.113	46444.48
0	116416.8	31166.69	0	91.05563	3144.447	31166.69	3786.114	2830.558	47638.93
0	147666.8	43416.7	0	100.3612	2936.113	43416.7	4750.004	3369.447	66222.28
0	195889	60611.16	0	139.4446	2641.669	60611.16	4663.893	3416.669	89777.85
0	250833.5	87111.18	0	182.3335	2461.669	87111.18	4355.559	2983.336	98833.41
0	303889.1	105139	0	246.4724	2755.28	105139	5413.893	2442.78	100639
0	359444.7	117000.1	0	283.0558	3888.892	117000.1	8466.673	1726.39	94972.3
0	406667	128777.9	0	344.1669	5775.005	128777.9	13436.12	1426.668	82472.29
0	440278.1	132805.7	0	555.8338	7852.784	132805.7	21583.35	2684.724	77166.73
0	439167	127916.8	0	1148.056	9100.007	127916.8	34972.25	5347.227	67777.83
0	425000.3	124027.9	0	1907.502	9997.23	124027.9	51666.71	9141.674	54388.93

Primary energy (oil, CCS)	Primary energy (oil, no CCS)	Primary energy (other)	Primary energy (solar)	Primary energy (trad biomass)	Primary energy (wind)	Temperature	GDP per capita	Final energy (kWh)	Final energy per capita
0	48557.37	58.80305	4.572004	10553.69	103.8741	0.913386	8790.668	9.47E+13	14494.95
0	47700.82	68.65305	33.72603	11266.13	341.3472	0.989362	9890.766	1.02E+14	14739.31
60.15738	42964.06	99.15289	501.432	5952.919	1274.182	1.237116	13439	9.63E+13	12708.83
286.8897	23766.49	168.028	894.0568	2981.283	1580.485	1.466178	19332.18	7.63E+13	9470.211
531.0168	11579.33	515.5099	7272.867	2594.486	4574.711	1.557877	26606.49	8.03E+13	9569.036
408.322	8949.177	593.7719	13361.28	2290.657	8476.393	1.562219	34148.22	8.91E+13	10440.1
165.7848	7775.545	723.6147	18447.9	1829.056	8744.824	1.528371	41955.26	9.56E+13	11262.77
169.9748	6996.219	937.2774	22139.71	1358.427	6846.803	1.49271	50523.4	1E+14	12074.96
192.2911	6254.972	1165.719	24957.51	1036.26	7019.363	1.45588	59670.65	1.02E+14	12796.23
178.0199	5717.538	1361.028	25981.03	735.7428	8291.848	1.410488	69886.03	1.01E+14	13464.37
121.0128	5359.032	1570.177	25328.45	446.8262	7559.529	1.344853	81257.62	9.88E+13	14198.89
0	48557.37	58.80305	4.572004	10553.69	103.8741	0.913386	8790.668	9.47E+13	14494.95
0	47700.82	68.65305	33.72603	11266.13	341.3472	0.98863	9890.766	1.02E+14	14739.31
2.80E-14	47542.43	106.7054	443.5454	6417.03	1217.251	1.218161	13439	1.07E+14	14123.69
6.581449	41439.09	285.9605	1573.745	3881.47	2573.819	1.472536	19332.18	1.11E+14	13738.01
142.0418	33751.03	553.1743	5834.385	3474.336	4495.641	1.654554	26606.49	1.15E+14	13747.22
158.1949	30412.88	676.4897	13178.64	2877.05	6758.502	1.759317	34148.22	1.19E+14	13939.32
87.85974	27549.75	828.3998	19741.87	2267.683	8140.421	1.811741	41955.26	1.23E+14	14492.35
18.24386	23279.75	983.9516	24636.84	1702.658	8481.664	1.835215	50523.4	1.22E+14	14736.31
12.3367	15147.8	1173.584	27065.32	1261.484	8357.076	1.834751	59670.65	1.18E+14	14830.13
5.296621	10708.86	1382.894	26964.88	877.8849	7255.889	1.803641	69886.03	1.15E+14	15330.14
6.448497	10237.33	1553.563	31911.92	549.7346	7407.514	1.761081	81257.62	1.16E+14	16639.93
0	48557.37	58.80305	4.572004	10553.69	103.8741	0.913386	8790.668	9.47E+13	14494.95
0	47700.82	68.65305	33.72603	11266.13	341.3472	0.988462	9890.766	1.02E+14	14739.31
1.27E-18	48639.93	108.4494	441.6745	6524.672	1212.521	1.221132	13439	1.1E+14	14487.01
2.84E-06	44002.26	286.5663	1255.331	4207.931	2318.238	1.492611	19332.18	1.2E+14	14846.83
0.000192	38148.14	567.6949	4074.986	3976.664	4427.535	1.714407	26606.49	1.31E+14	15630.14
0.000563	36473.22	747.4342	10783.32	3418.961	7301.795	1.8992	34148.22	1.4E+14	16434.75
1.066966	33878.03	915.1774	18352.01	2730.274	8285.22	2.03953	41955.26	1.45E+14	17098.98
2.158196	28697.22	1040.737	25927.05	2036.958	9159.185	2.150535	50523.4	1.42E+14	17098.66
2.231133	19927.32	1184.507	29919.19	1462.251	9870.641	2.219817	59670.65	1.32E+14	16580.28
3.998687	12097.56	1352.781	29902.09	967.5258	9288.168	2.230802	69886.03	1.24E+14	16496.4
4.567112	9359.749	1559.835	30937.02	563.2296	8361.768	2.193107	81257.62	1.21E+14	17334.19
0	48557.37	58.80305	4.572004	10553.69	103.8741	0.913386	8790.668	9.47E+13	14494.95
0	47700.82	68.65305	33.72603	11266.13	341.3472	0.988451	9890.766	1.02E+14	14739.31
5.01E-18	48604.62	108.4665	441.0525	6525.575	1211.584	1.221551	13439	1.1E+14	14485.58
0.016411	44372.04	286.6211	1190.635	4279.289	2230.372	1.494779	19332.18	1.21E+14	15053.8

0.016361	39375.7	568.5977	3408.095	4186.184	4147.916	1.725589	26606.49	1.37E+14	16355.87
0.010709	38643.75	811.5423	8718.397	3688.761	6919.92	1.936466	34148.22	1.5E+14	17615.63
0.000514	36643.84	993.8858	14851.76	2989.461	8118.537	2.137401	41955.26	1.57E+14	18526.63
0.001145	31948.91	1143.362	23541.75	2290.96	8572.276	2.325398	50523.4	1.57E+14	18865.66
0.03435	23651.34	1287.574	30085.7	1721.051	9698.682	2.476998	59670.65	1.49E+14	18737.05
5.712482	16635.64	1432.233	32544.68	1168.176	10352.47	2.585335	69886.03	1.39E+14	18488.77
4.87359	12434.35	1583.128	33286.2	669.982	9921.527	2.652743	81257.62	1.3E+14	18704.06
0	48557.37	58.80305	4.572004	10553.69	103.8741	0.913386	8790.668	9.47E+13	14494.95
0	47700.82	68.65305	33.72603	11266.13	341.3472	0.988441	9890.766	1.02E+14	14739.31
0	48637.37	108.5403	440.7903	6526.647	1211.108	1.222835	13439	1.1E+14	14492.14
0	44336.95	286.6319	1174.396	4274.045	2203.281	1.505786	19332.18	1.22E+14	15095.51
0	39617.92	568.6196	3267.944	4230.42	4077.902	1.770743	26606.49	1.39E+14	16561.01
0	39270.56	823.0454	8177.612	3744.603	6768.503	2.022057	34148.22	1.52E+14	17831.44
0	37742.73	1013.104	13644.48	3068.519	7888.962	2.246411	41955.26	1.61E+14	19011.02
0	33786.67	1190.54	21189.27	2419.758	8296.056	2.46035	50523.4	1.65E+14	19916.95
0	25938.95	1371.212	28926.88	1892.147	9116.941	2.668723	59670.65	1.63E+14	20430.42
0	19315.21	1522.214	32575.96	1324.84	9191.266	2.856211	69886.03	1.56E+14	20772.72
0	15063.13	1691.641	32737.33	778.1809	8833.68	3.017736	81257.62	1.47E+14	21091.25
	47939.21	0	85.55562	8144.784	106.389	0.913386	8693.168	8.97E+13	13800.29
	48078.37	0	688.3339	8473.087	460.2781	0.989048	9829.892	1E+14	14631.6
	57878.66	0	2891.391	7867.229	1856.668	1.241434	13256.35	1.22E+14	16013.15
	46715.59	0	7355.839	7269.714	6559.172	1.502207	17087.47	1.18E+14	14249.94
	27713.63	0	12300.57	6240.838	13941.96	1.627379	20595.87	1.17E+14	13282.93
	9306.119	0	17775.85	5005.129	19836.68	1.64476	24349.11	1.22E+14	13272.59
	3833.336	0	22417.52	3635.828	25383.35	1.616748	28659.24	1.32E+14	14012.51
	2894.725	0	27799.74	2247.521	32781.97	1.569317	33973.31	1.41E+14	14882.27
	2210.28	0	32533.64	750.47	41065.03	1.503767	40183.39	1.5E+14	15984.42
	1321.112	0	39653.92	0	49257.54	1.424558	47372.05	1.6E+14	17299.41
	790.834	0	50274.48	0	59210.33	1.336877	55863.78	1.72E+14	19012.21
	47954.21	0	85.55562	8144.784	107.5001	0.913386	8693.168	8.97E+13	13798.49
	48088.37	0	688.6117	8473.087	461.3893	0.989073	9831.668	1.01E+14	14636.17
	57598.38	0	2953.891	7867.229	1853.057	1.241272	13280.54	1.22E+14	16005.05
	57046.16	0	6151.672	7269.714	4671.393	1.492433	17243.16	1.33E+14	16055.27
	53204.76	0	10017.79	6240.838	7874.729	1.696799	20992.51	1.4E+14	15943.01
	39233.09	0	13806.96	5005.129	11325.01	1.809846	24922.56	1.46E+14	15913.59
	26549.74	0	17708.63	3635.828	15277.79	1.853236	29466.69	1.56E+14	16581.79
	11466.95	0	23205.57	2247.521	20407.79	1.861529	34987.38	1.65E+14	17460.44
	3722.225	0	28758.08	750.47	29787.8	1.844434	41463.49	1.77E+14	18763.24
	1458.335	0	35318.08	0	42954.76	1.807019	49101.35	1.88E+14	20269.26
	663.3339	0	43891.98	0	58303.94	1.754633	58093.56	2.01E+14	22273.83
	47954.21	0	85.55562	8144.784	107.5001	0.913386	8693.168	8.97E+13	13798.49
	48088.37	0	688.6117	8473.087	461.3893	0.989049	9832.498	1.01E+14	14636.17
	57669.21	0	2909.447	7867.229	1842.224	1.242073	13290.67	1.22E+14	16006.44
	61837.27	0	5904.727	7269.714	3685.003	1.492368	17295.13	1.39E+14	16778.69
	62512.55	0	9570.841	6240.838	6665.005	1.737479	21097.86	1.52E+14	17331.09
	57249.77	0	12851.4	5005.129	10070.84	1.918756	25104.57	1.63E+14	17725.62
	44621.42	0	16462.79	3635.828	13736.96	2.050532	29688.43	1.7E+14	18074.08

34438.92	0	19806.96	2247.521	16833.35	2.14427	35337.86	1.82E+14	19247.17
21323.63	0	23394.19	750.47	20825.57	2.200498	41933.38	1.95E+14	20687.26
10363.34	0	29121.13	0	29874.47	2.220768	49697.79	2.06E+14	22281.52
5146.671	0	35426.97	0	42077.26	2.212415	58890.66	2.21E+14	24501.91
47954.21	0	85.55562	8144.784	107.5001	0.913386	8693.168	8.97E+13	13798.49
48088.37	0	688.6117	8473.087	461.3893	0.989027	9832.688	1.01E+14	14636.17
57663.66	0	2887.225	7867.229	1665.557	1.242266	13297.25	1.22E+14	16035.34
61943.94	0	5756.116	7269.714	3625.558	1.485988	17310.45	1.42E+14	17128.72
64877	0	9186.396	6240.838	6074.449	1.743192	21137.41	1.58E+14	18036.13
64183.66	0	12298.07	5005.129	8940.285	1.966494	25174.9	1.72E+14	18710.91
55193.66	0	14952.51	3635.828	13221.12	2.154152	29810.93	1.81E+14	19281.69
42633.65	0	18218.9	2247.521	16448.9	2.317638	35497.94	1.92E+14	20346.14
32180.3	0	21101.68	750.47	18918.63	2.458626	42145.93	2.07E+14	21999.4
21713.07	0	25868.08	0	21806.13	2.566724	49988.71	2.22E+14	23943.19
14348.07	0	29749.47	0	28912.52	2.629087	59259.4	2.38E+14	26302.13
47954.21	0	85.55562	8144.784	107.5001	0.913386	8693.168	8.97E+13	13798.49
48088.37	0	688.6117	8473.087	461.3893	0.989018	9833.081	1.01E+14	14636.17
57738.94	0	2887.225	7867.229	1630.279	1.242303	13300.46	1.22E+14	16042.31
62636.99	0	5756.949	7269.714	3245.28	1.481852	17313.4	1.43E+14	17333.95
66032.55	0	8865.007	6240.838	5197.226	1.754337	21154.52	1.62E+14	18398.09
67171.44	0	11336.68	5005.129	7971.951	2.025425	25215.99	1.77E+14	19265.46
61087.27	0	14085.84	3635.828	11746.4	2.286602	29871.88	1.9E+14	20192.99
55349.49	0	16575.29	2247.521	15788.9	2.545365	35598.11	2.02E+14	21353.17
60897.55	0	19317.79	750.47	19493.35	2.786019	42312.35	2.2E+14	23365.1
67729.78	0	22671.96	0	22352.24	3.011456	50267.8	2.4E+14	25929.13
71854.22	0	25762.8	0	23448.35	3.229339	59608.05	2.61E+14	28907.84
47947.82	0	85.55562	8144.784	107.5001	0.913386	8693.168	8.97E+13	13798.37
48088.93	0	688.6117	8473.087	461.3893	0.988977	9833.255	1.01E+14	14636.17
57572.82	0	2887.225	7867.229	1528.89	1.241407	13301.95	1.22E+14	16070.08
62710.61	0	5698.338	7269.714	2849.447	1.48262	17316.62	1.44E+14	17459.05
66860.89	0	8644.729	6240.838	4630.281	1.761503	21162.18	1.63E+14	18561.46
68357.83	0	11085.29	5005.129	6837.505	2.052806	25226.03	1.79E+14	19507.88
63125.61	0	13622.79	3635.828	9982.23	2.356264	29890.72	1.93E+14	20550.28
57784.77	0	15812.51	2247.521	13579.46	2.681335	35619.41	2.07E+14	21910.29
64650.33	0	17291.96	750.47	15629.73	3.023154	42360.71	2.26E+14	24069.05
75016.45	0	19151.4	0	18958.07	3.387957	50340.29	2.48E+14	26762.14
82947.01	0	21931.41	0	23475.02	3.76329	59710.73	2.71E+14	29948.99
0	45625.45	9.666674	2.833336	102.139	0.913386	8431.4	9.28E+13	14300.21
0	48948.01	9.555563	26.00002	125.139	0.988307	9420.344	1E+14	14582.31
0	59300.08	10.55556	58.66671	307.7502	1.229122	12652.99	1.23E+14	15953.58
0	63841.58	11.61112	295.4725	1256.084	1.515949	15275.35	1.4E+14	16423.37
2839.169	57210.21	12.47223	1293.557	3202.503	1.828829	16242.24	1.28E+14	13872.38
9538.369	47747.23	13.02779	2695.391	4839.754	1.989656	16718.17	1.33E+14	13375.45
13952.48	38462.45	13.36112	4021.864	7187.422	2.07976	17059.94	1.37E+14	12957.29
13124.57	31141.52	13.58334	5805.755	10967.65	2.146508	17519.24	1.38E+14	12374.22
11999.59	24922.8	13.55557	8530.868	15267.26	2.188886	18004.77	1.39E+14	11976.57
10429.04	19901.52	13.3889	11724.87	20629.1	2.210887	18511.78	1.43E+14	11793.86

8893.979	16404.51	13.19446	15502.9	26159.83	2.211311	19205.9	1.49E+14	11830.15
0	45625.45	9.666674	2.833336	102.139	0.913386	8431.4	9.28E+13	14300.21
0	48948.01	9.555563	26.00002	125.139	0.988307	9420.344	1E+14	14582.31
0	59300.08	10.55556	58.66671	307.7502	1.230334	12652.99	1.23E+14	15953.58
0	65969.44	11.11112	223.9446	901.4174	1.522074	15293.9	1.43E+14	16839.06
0	66977.28	11.02779	734.5006	1900.113	1.841247	16482.92	1.43E+14	15469.7
1400.501	63122.61	11.47223	1635.668	3047.502	2.06258	17044.57	1.47E+14	14776.18
4994.615	52414.1	11.75001	2795.724	5001.226	2.236536	17322.18	1.47E+14	13882.77
9734.23	44945.67	11.94445	3711.781	6769.117	2.362402	17897.66	1.51E+14	13603.94
12228.01	38229.92	11.91668	4841.782	9145.98	2.465828	18538.32	1.55E+14	13325.18
11813.87	33678.78	11.77779	6627.644	12537.45	2.554043	19167.94	1.58E+14	13058.82
11125.84	28463.88	11.58334	9305.813	17063.1	2.617403	19867.22	1.62E+14	12800.22
0	45625.45	9.666674	2.833336	102.139	0.913386	8431.4	9.28E+13	14300.21
0	48948.01	9.555563	26.00002	125.139	0.988307	9420.344	1E+14	14582.31
0	59300.08	10.55556	58.66671	307.7502	1.230793	12652.99	1.23E+14	15953.58
0	66107.44	10.94445	219.6946	880.3896	1.52418	15295.08	1.44E+14	16871.54
0	68577.36	10.6389	619.2505	1630.029	1.844651	16567.18	1.5E+14	16176.95
0	67318.75	10.52779	1255.807	2375.53	2.099352	17224.24	1.56E+14	15700.25
0	64074.55	10.77779	1801.168	3259.947	2.333273	17723.15	1.64E+14	15512.2
218.4446	60965.69	10.97223	2421.446	4383.726	2.58092	18357.12	1.69E+14	15156.9
1342.112	56607.27	10.94445	3278.308	5957.449	2.806649	19026.74	1.73E+14	14846.58
1963.613	53646.29	10.80556	4154.809	7680.867	3.005281	19785.93	1.8E+14	14820.66
3117.808	49515.18	10.6389	5145.032	9792.952	3.183591	20724.26	1.88E+14	14877.41
	45625.45	9.666674	2.833336	102.139	0.913386	8431.4	9.28E+13	14300.21
	49061.57	9.555563	25.83335	125.4723	0.988055	9421.015	1E+14	14608.01
	60254.49	10.55556	42.50003	165.2501	1.225753	12659.11	1.25E+14	16183.31
	67431.47	11.61112	72.63895	217.5002	1.523809	15315.63	1.46E+14	17151.13
	70758.14	12.47223	117.9723	277.1669	1.864192	16697.99	1.61E+14	17409.83
	69415.5	13.02779	178.6946	330.4169	2.202509	17440.16	1.72E+14	17279.38
	66032.03	13.36112	237.2502	444.0281	2.550932	17975.93	1.8E+14	17050.6
	63575.13	13.58334	305.528	578.7782	2.911519	18700.1	1.89E+14	16958.08
	60997.97	13.55557	409.3614	778.9728	3.284348	19489.89	1.97E+14	16920.96
	59563.41	13.3889	529.1671	1010.279	3.672423	20362.15	2.06E+14	17017.75
	56900.82	13.19446	678.9172	1303.029	4.0711	21415.38	2.16E+14	17145.87
0	48910.83	33.47359	8491.139	341.7173	0.98868	9706.811	1.09E+14	15865.01
44.25278	52687.65	487.8533	9495.258	1594.598	1.232684	13091.2	1.32E+14	17258.77
340.1738	49556.48	1612.895	11071.58	5149.813	1.507354	17134.43	1.39E+14	16789.39
461.392	46490.8	3529.754	11745.65	7933.148	1.68673	20809.4	1.49E+14	16982.51
538.4816	41459.17	6318.113	12244.63	9875.47	1.794301	23945.28	1.54E+14	16847.49
479.2541	31710.23	9835.376	12604.08	10096.38	1.865045	26820.64	1.56E+14	16665.87
401.9085	22746.68	13577.58	12733.68	11028.85	1.909638	29732.64	1.57E+14	16573.18
323.8311	14414.7	17430.34	12654.5	12531.71	1.928478	32446.68	1.56E+14	16514.71
211.6517	8077.164	22819.56	12119.17	14954.36	1.892715	35121.67	1.56E+14	16587.31
84.28006	3706.808	27581.92	10825.39	16058.59	1.799397	37893.19	1.58E+14	17049.21
0	48910.83	33.47343	8491.139	341.7174	0.98868	9706.811	1.09E+14	15865.01

44.2492	52687.65	487.8533	9495.258	1594.598	1.231585	13089.16	1.32E+14	17258.77
141.3829	52451.51	1279.284	10680.94	3632.848	1.483902	17103.95	1.45E+14	17594.57
219.7695	51549.08	2931.221	11247.29	6292.577	1.712703	20811.18	1.57E+14	17904.78
327.6789	49222.03	5494.082	11662.09	8486.905	1.895201	23955.95	1.63E+14	17785.64
445.8955	42606.99	8860.824	11947.39	9692.804	2.019821	26833.11	1.65E+14	17568.28
439.4754	35920.47	12579.8	12026.73	10174.95	2.110105	29747.96	1.65E+14	17406.2
403.9485	26947.73	15914.75	11970.65	10852.05	2.17456	32453.26	1.63E+14	17221.93
341.9064	17762.59	20195.87	11594.09	12688.16	2.206742	35137.43	1.61E+14	17102.14
236.0736	11405.18	25740.25	10926.78	14735.23	2.186048	37890.07	1.59E+14	17142.65

0	48910.83	33.47343	8491.139	341.7174	0.98868	9706.811	1.09E+14	15865.01
44.22547	52687.68	487.8533	9495.258	1594.598	1.231278	13089.16	1.32E+14	17258.77
91.49143	53362.14	1158.853	10458.99	3148.892	1.480864	17103.95	1.49E+14	18020.88
127.5699	53260.43	2531.949	10967.67	5135.303	1.722219	20811.18	1.62E+14	18453.81
184.5796	52336.18	4779.242	11327.55	7086.068	1.941254	23955.95	1.68E+14	18413.71
317.6923	48196.36	8038.288	11559.2	8937.223	2.117408	26833.11	1.71E+14	18244.94
393.4593	44213.97	11758.94	11614.4	9917.334	2.250108	29747.96	1.71E+14	18065.98
246.2743	43760.97	14010.53	11158.75	9330.96	2.36523	32453.26	1.74E+14	18361.03
273.3348	43157.02	16120.34	10208.16	9155.227	2.450691	35137.43	1.75E+14	18588.92
284.7225	39645.66	19593.02	9396.814	10152.73	2.516387	37890.07	1.73E+14	18662.7

0	48910.83	33.47343	8491.139	341.7174	0.98868	9706.811	1.09E+14	15865.01
44.00961	52687.89	487.8533	9495.258	1594.598	1.231	13089.16	1.32E+14	17258.77
49.85947	53597.08	1006.801	10061.38	2737.774	1.490755	17103.95	1.55E+14	18733.22
50.33079	54181.64	2032.219	10427.04	3961.883	1.777343	20811.18	1.7E+14	19447.44
49.23971	54852.33	3510.729	10582.59	4533.673	2.053811	23955.95	1.8E+14	19715.81
65.56506	53868.14	5512.246	10501.48	5230.114	2.311553	26833.11	1.86E+14	19884.74
71.13257	55783.91	7717.294	10245.25	5706.592	2.560291	29747.96	1.9E+14	20008.24
94.14153	56888.41	10418.8	9820.371	7086.295	2.802207	32453.26	1.89E+14	20001.29
128.0455	56226.55	13768.81	9176.197	8670.85	3.004306	35137.43	1.87E+14	19933.11
162.9043	53439.87	18262.63	8539.322	10262.53	3.156524	37890.07	1.85E+14	19860.6

0	47349.72	4.540956	7938.579	103.9778	0.913386	8716.302	9.97E+13	15328.51
0	48910.83	33.47343	8491.139	341.7174	0.988562	9706.811	1.09E+14	15865.01
0	53132.06	455.4946	9405.006	1442.737	1.237213	13089.16	1.34E+14	17521.86
0	52381.21	974.5734	9981.251	2608.658	1.532875	17103.95	1.56E+14	18840.48
0	52064.62	1943.509	10313.45	3744.478	1.873893	20811.18	1.72E+14	19606.37
0	52238.01	3306.326	10339.7	4285.926	2.216306	23955.95	1.82E+14	19935.42
0	50679.03	5114.856	10182.43	4743.325	2.546151	26833.11	1.89E+14	20204.39
0	52747.69	7002.736	9828.849	4959.187	2.87451	29747.96	1.94E+14	20468.74
0	54759.92	9030.877	9182.252	5825.461	3.200995	32453.26	1.96E+14	20655.41
0	55866.81	11028.05	8450.834	6581.459	3.494213	35137.43	1.96E+14	20850.96
0	56206.87	13167.79	7754.914	7220.4	3.758289	37890.07	1.96E+14	21127.42
	46444.48	1.722224	9186.118	106.9445	0.913386	8714.835	9.19E+13	14121.63
	47638.93	65.72227	9397.23	483.8893	0.989287	9801.276	9.9E+13	14360.32
	65666.72	458.6115	6433.338	1328.334	1.259486	13493.11	1.25E+14	16581.35
	88833.4	931.9452	2913.891	2975.002	1.536892	20213.56	1.37E+14	17027.44
	69000.06	5055.56	809.7229	7283.339	1.729645	29346.66	1.33E+14	15804.55

32166.69	18077.79	0	13405.57	1.809724	39445.16	1.42E+14	16571.49
8133.34	36555.58	0	19175.02	1.777239	51298.17	1.5E+14	17496.55
3744.447	54222.27	0	23825.02	1.689111	66217.33	1.71E+14	20196.96
3030.558	71250.06	0	28111.13	1.589518	83719.51	1.91E+14	23313.03
2632.224	87777.85	0	32472.25	1.487402	104584.3	2.1E+14	26791.69
2409.169	102861.2	0	34361.14	1.374447	130183.1	2.25E+14	30467.07
46444.48	1.722224	9186.118	106.9445	0.913386	8714.835	9.19E+13	14121.63
47638.93	65.72227	9397.23	483.8893	0.989291	9801.276	9.9E+13	14360.32
65666.72	458.6115	6433.338	1328.334	1.259341	13493.11	1.25E+14	16581.35
92777.85	515.2782	2913.891	2257.78	1.547275	20449.47	1.5E+14	18586.36
95250.08	1408.612	809.7229	4533.337	1.795001	30286.8	1.61E+14	19126.78
75861.17	6366.672	0	8797.229	1.96702	40983.8	1.73E+14	20139.63
42166.7	18850.02	0	13844.46	2.048924	53091.16	1.76E+14	20446.06
18763.9	37555.59	0	19216.68	2.058	68203.85	1.85E+14	21855.68
7677.784	59833.38	0	24741.69	2.017137	85768.29	1.99E+14	24237.82
3069.447	81166.73	0	30722.25	1.933609	106448.7	2.14E+14	27359.24
2509.446	97944.52	0	33305.58	1.823153	132230.5	2.3E+14	31156.33
46444.48	1.722224	9186.118	106.9445	0.913386	8714.835	9.19E+13	14121.63
47638.93	65.72227	9397.23	483.8893	0.989292	9801.276	9.9E+13	14360.32
65666.72	458.6115	6433.338	1328.334	1.259449	13493.11	1.25E+14	16581.35
88250.07	445.2781	2913.891	1991.113	1.554135	20461.88	1.51E+14	18769.16
95500.08	602.7783	809.7229	3300.003	1.838677	30441.51	1.69E+14	20072.21
91638.96	2442.78	0	6355.561	2.057854	41426.74	1.87E+14	21790.95
72527.84	9991.675	0	10480.56	2.201463	53859.59	1.95E+14	22667.9
44611.15	25047.24	0	15316.68	2.298636	69055.22	1.99E+14	23530.82
24636.13	46944.48	0	21272.24	2.341335	86987.8	2.09E+14	25528.48
13547.23	69722.28	0	27833.36	2.322814	108172.6	2.22E+14	28313.42
9519.452	88527.85	0	31027.8	2.252036	133789.8	2.33E+14	31574.41
46444.48	1.722224	9186.118	106.9445	0.913386	8714.835	9.19E+13	14121.63
47638.93	65.72227	9397.23	483.8893	0.989292	9801.276	9.9E+13	14360.32
65666.72	458.6115	6433.338	1328.334	1.259498	13493.11	1.25E+14	16581.35
88055.63	436.3892	2913.891	1982.502	1.555131	20474.3	1.52E+14	18882.97
95500.08	428.3337	809.7229	3119.447	1.856649	30512.91	1.73E+14	20594.51
94194.52	1224.723	0	5608.338	2.108722	41659.87	1.96E+14	22898.31
81888.95	5847.227	0	8911.118	2.291695	54325.3	2.11E+14	24527.52
60972.27	16250.01	0	12938.9	2.438038	69705.57	2.19E+14	25866.17
50194.48	32500.03	0	17861.13	2.556399	88146.34	2.33E+14	28434.98
43416.7	50027.82	0	23358.35	2.637877	110228.6	2.44E+14	31140.51
41416.7	63555.61	0	26236.13	2.683349	137220.3	2.58E+14	34986.85
46444.48	1.722224	9186.118	106.9445	0.913386	8714.835	9.19E+13	14121.63
47638.93	65.72227	9397.23	483.8893	0.989292	9801.276	9.9E+13	14360.32
65666.72	458.6115	6433.338	1328.334	1.259277	13493.11	1.25E+14	16581.35
88472.29	433.6115	2913.891	1798.613	1.554898	20536.38	1.56E+14	19389.97
97500.08	326.1114	809.7229	2281.668	1.8858	30739.02	1.85E+14	21976.3
98250.08	294.7225	0	3666.67	2.216687	42091.15	2.13E+14	24853.99
90361.18	1944.168	0	5850.005	2.513596	54977.3	2.34E+14	27211.83
77416.73	7647.228	0	9700.008	2.781248	70509.64	2.48E+14	29328.13

73250.06	18188.9	0	14755.57	3.009628	88914.63	2.61E+14	31869.94
65777.83	33194.47	0	20319.46	3.189769	111148	2.68E+14	34283.29
57916.71	49305.6	0	23238.91	3.327655	138305.1	2.8E+14	37928.47
46444.48	1.722224	9186.118	106.9445	0.913386	8714.835	9.19E+13	14121.63
47638.93	65.72227	9397.23	483.8893	0.989124	9801.276	9.9E+13	14360.32
66222.28	458.6115	6433.338	1253.89	1.265801	13493.11	1.25E+14	16570.31
89777.85	433.6115	2913.891	1448.057	1.60296	20586.04	1.6E+14	19841.78
98833.41	313.3336	809.7229	1398.612	2.01275	30965.13	1.98E+14	23539.89
100639	43.50003	0	2367.502	2.48049	42510.78	2.33E+14	27123.75
94972.3	103.4445	0	4191.67	2.975504	55687.51	2.61E+14	30413.6
82472.29	791.1117	0	6525.005	3.503795	71632.97	2.85E+14	33699.92
77166.73	3691.67	0	9486.119	4.0499	90317.07	3.08E+14	37533.91
67777.83	11136.12	0	13575.01	4.575695	112667.6	3.17E+14	40473.08
54388.93	22469.46	0	17286.12	5.051967	139796.6	3.24E+14	43954.84

Primary energy per capita	CO2 emissions per capita	Methane emisisions per capita	Nitrous oxide emissions per capita		Primary energy (% fossil)	Primary energy (% fossil CCS)	Primary energy (% coal)	Primary energy (% coal CCS)	Primary energy (% gas)	Primary energy (% gas CCS)
19524.63	5.078605	0.048755	0.001402	85.8852	0	25.5937	0	22.20923	0	
20301.51	5.127111	0.050256	0.00142	84.90192	0	28.65972	0	22.29699	0	
17717.18	4.383361	0.039581	0.001224	84.33913	0.425782	25.72294	0.0899	26.56291	0.291064	
13663.77	2.228741	0.026716	0.000942	71.83293	6.296393	14.95157	0.865161	35.04571	5.170794	
13232.66	0.764588	0.021328	0.000915	55.46905	21.26424	7.46109	2.601379	37.09829	18.18449	
14037.73	0.113479	0.017985	0.000888	47.67697	26.01147	5.713096	3.694534	34.1496	21.97595	
15129.18	-0.1943	0.016982	0.000895	42.77815	26.40641	5.394406	4.292189	31.20274	21.98519	
16563.48	-0.49849	0.016371	0.000935	39.3019	26.79873	5.33272	4.468459	28.75587	22.20662	
17609.08	-0.92505	0.015779	0.001004	31.82977	21.5354	4.602757	3.914173	22.63162	17.48417	
18337.22	-1.40707	0.015589	0.001081	24.39037	15.46699	3.541162	2.966763	16.5684	12.37096	
19559.95	-2.061	0.015766	0.001193	18.57704	10.19158	2.392365	1.923926	12.15813	8.178738	
19524.63	5.078605	0.048755	0.001402	85.8852	0	25.5937	0	22.20923	0	
20301.51	5.12711	0.050256	0.00142	84.90192	0	28.65972	0	22.29697	0	
19967.42	5.067219	0.041555	0.001244	86.67887	1.98E-12	27.953	1.88E-12	27.29812	1.04E-13	
19196.77	4.20878	0.031936	0.001027	83.85839	1.207527	23.7657	0.863042	33.31263	0.340232	
18318.05	3.088028	0.02624	0.000923	76.03586	6.599247	17.5393	3.795309	36.44019	2.711502	
17981.27	2.078768	0.022318	0.00089	66.93619	9.614476	12.08633	5.481054	34.91947	4.030289	
18712.69	1.244181	0.020648	0.000894	57.22772	11.84035	9.448647	7.366728	30.38724	4.418339	
19065.28	0.576608	0.018936	0.000929	48.44177	12.58529	9.080738	7.844675	24.63614	4.729088	
19815.65	-0.36673	0.017005	0.001007	37.86934	12.62934	7.966911	7.001938	20.30004	5.619593	
21075.93	-1.07827	0.017075	0.001137	31.57092	12.06249	7.114524	6.336706	17.6877	5.722439	
22476.93	-1.19968	0.017293	0.001201	29.81389	10.84192	5.331619	4.752449	17.9323	6.085344	
19524.63	5.078605	0.048755	0.001402	85.8852	0	25.5937	0	22.20923	0	
20301.93	5.12711	0.050256	0.00142	84.90014	0	28.65912	0	22.29651	0	
20553.5	5.232081	0.046785	0.001324	86.8736	5.38E-15	28.28641	5.09E-15	27.35077	2.83E-16	
21067.54	4.881134	0.038363	0.001189	85.24992	0.001495	26.43555	0.001458	32.9071	3.62E-05	
21332.92	4.463485	0.032066	0.001051	80.59308	0.031995	22.68287	0.029685	36.59325	0.00231	
21569.71	3.86229	0.028071	0.000973	74.97745	0.334773	17.91062	0.287994	37.24447	0.046778	
22051.25	3.291922	0.025273	0.000937	68.91432	1.63229	14.53203	1.265642	36.29057	0.366078	
21610.68	2.387444	0.021588	0.000925	59.73585	4.707122	12.63624	3.07292	31.09737	1.632998	
21261.67	1.145089	0.019413	0.000965	47.74472	7.888701	10.74744	5.290644	25.23249	2.596739	
22085.02	-0.30297	0.017923	0.001095	34.63062	9.361215	8.675069	6.192595	18.65967	3.166208	
23716.02	-0.95077	0.018756	0.001252	29.20391	8.904856	7.362072	6.085171	16.16704	2.816918	
19524.63	5.078605	0.048755	0.001402	85.8852	0	25.5937	0	22.20923	0	
20301.93	5.12711	0.050256	0.00142	84.90016	0	28.65913	0	22.29651	0	
20565.03	5.261294	0.047231	0.00133	86.78872	4.93E-15	28.30947	4.67E-15	27.283	2.59E-16	
21451.67	5.080428	0.041098	0.001239	85.6733	0.000802	27.15026	0.000766	32.86587	2.6E-05	

22693.95	4.946927	0.037181	0.001174	82.02639	0.005216	25.36435	0.004811	35.97872	0.000396
23896.6	4.691515	0.034935	0.001145	77.92376	0.012814	22.91746	0.012273	36.04931	0.000535
24784.54	4.44347	0.031276	0.001085	73.92138	0.037251	21.15331	0.036688	35.35797	0.000563
24770.3	3.89483	0.027578	0.001026	66.79813	0.096172	18.23172	0.095374	33.0246	0.000797
24198.91	3.069469	0.02403	0.001001	57.52143	0.879374	14.57179	0.545675	30.68246	0.333682
23761.26	2.304477	0.02159	0.001038	49.26531	2.20604	11.8361	1.242314	28.10413	0.960525
24076.97	1.592277	0.020051	0.001101	42.75111	3.170374	9.3546	1.740583	25.97131	1.426882
19524.63	5.078605	0.048755	0.001402	85.8852	0	25.5937	0	22.20923	0
20301.93	5.12711	0.050256	0.00142	84.90016	0	28.65913	0	22.29651	0
20574.22	5.288866	0.048262	0.001346	86.78001	0	28.31765	0	27.25905	0
21526.92	5.290692	0.047282	0.001304	85.33983	0	27.30022	0	32.49234	0
23062.08	5.218707	0.046473	0.001266	82.15983	0	25.93932	0	35.74214	0
24364.97	4.976819	0.044488	0.001231	78.94242	0	24.11625	0	35.93204	0
25793.32	4.898854	0.04265	0.001209	75.73474	0	23.43217	0	35.0717	0
26888.87	4.725602	0.040811	0.001224	70.4649	0	22.67572	0	32.64835	0
27226.66	4.191122	0.038276	0.001257	62.91521	0	20.24979	0	30.70788	0
27558.41	3.810477	0.036389	0.001308	57.80858	0	18.32829	0	30.14819	0
27972.08	3.53736	0.035385	0.001354	55.2398	0	16.49562	0	31.00479	0
19837.6	5.807548	0.0514	0.001274	84.91311	0	26.11692	0	21.63588	0
20226	5.87028	0.047442	0.001274	83.72467	0	27.99962	0	21.11135	0
20972.88	5.37774	0.043311	0.001257	81.22756	0	23.73844	0	21.23108	0
17118.6	2.860464	0.032396	0.001183	67.4325	4.408625	6.919422	1.929056	27.48306	2.479569
16197.9	1.31148	0.025028	0.001049	51.38115	14.08495	4.673125	4.325544	27.23703	9.759406
16658.85	0.412136	0.020944	0.000894	36.30194	16.5952	6.967601	6.94105	23.24182	9.654148
17923.75	-0.16097	0.018015	0.00079	23.63777	10.79825	5.310361	5.301444	16.0485	5.496803
19145.07	-0.6916	0.015515	0.000693	14.55226	4.592744	2.381139	2.376229	10.57229	2.216515
20552.73	-1.12773	0.013548	0.00065	9.801147	1.142749	0.566059	0.563185	8.091908	0.579564
22349.3	-1.34114	0.012211	0.000609	7.468145	0.10409	0.105164	0.103553	6.724205	0.000537
24673.24	-1.44467	0.01143	0.000581	6.938247	0.005235	0.005858	0.004986	6.57753	0.000249
19839.27	5.808099	0.051402	0.001274	84.91416	0	26.11645	0	21.6289	0
20264.14	5.867487	0.047547	0.001275	83.54592	0	27.89062	0	21.09956	0
20949.09	5.341694	0.043452	0.001259	80.84266	0.035017	23.55409	0.010801	21.16513	0.024215
19768.15	4.180785	0.037268	0.001244	75.02989	2.406257	14.10215	1.038154	25.99959	1.368104
19549.49	2.993656	0.030676	0.001178	69.52464	8.926605	7.605499	3.146077	30.9472	5.780528
19995.75	1.781045	0.026622	0.001082	62.34972	20.9195	8.423341	7.060989	32.52767	13.85851
21300.59	0.985418	0.024079	0.001006	55.53153	25.86842	12.1197	11.45229	30.13029	14.41614
22991.36	0.212573	0.023019	0.000926	46.94513	26.56161	16.5075	16.30079	25.16369	10.26082
24565.41	-0.43007	0.021246	0.000833	37.71052	22.35211	15.91903	15.91663	20.18078	6.435479
26371.37	-0.70194	0.018998	0.000785	28.60162	16.11057	12.71904	12.71768	15.285	3.392898
28546.94	-0.92525	0.017257	0.000739	21.14307	10.26392	9.335611	9.334857	11.5502	0.929058
19839.27	5.808101	0.051402	0.001274	84.91416	0	26.11645	0	21.6289	0
20264.67	5.867481	0.047547	0.001275	83.54375	0	27.8899	0	21.09901	0
20969.96	5.476874	0.043814	0.001265	81.14733	0.022451	23.62445	0.009572	21.39102	0.012879
21175.84	5.087341	0.040795	0.001275	79.59215	0.523152	19.25485	0.511403	24.99254	0.011749
21313.19	4.34951	0.034318	0.001242	76.07344	2.31722	12.66306	1.953685	30.03146	0.363535
21961.01	3.556718	0.03027	0.001187	71.68571	5.691221	9.7603	4.160677	33.49427	1.530543
22820.67	2.589604	0.027381	0.001119	65.51581	12.52435	10.66818	6.966332	34.01259	5.55802

24576.34	1.630919	0.026341	0.001059	59.891	22.19662	13.3572	10.89836	31.71598	11.29826
26884.07	0.847689	0.025822	0.000958	54.86145	26.51267	16.3456	15.42167	30.08439	11.091
29116.87	0.200997	0.024917	0.000915	47.21099	26.07306	18.25197	17.95465	25.11286	8.118412
31904.45	-0.157	0.023521	0.000879	39.96513	23.0609	17.98902	17.97717	20.19014	5.083731
19839.27	5.8081	0.051402	0.001274	84.91416	0	26.11645	0	21.6289	0
20264.67	5.867483	0.047547	0.001275	83.54395	0	27.8899	0	21.09921	0
21030.76	5.555583	0.044123	0.001269	81.35767	0	23.96066	0	21.37308	0
21669.94	5.372272	0.041957	0.001284	80.57629	0.193319	21.63803	0.193319	24.33983	0
22349.24	5.063271	0.037802	0.001273	78.94516	0.867343	17.05053	0.867343	28.85909	0
23367.73	4.671354	0.034078	0.00124	76.46006	2.343325	14.42567	2.343325	32.07859	0
24432.4	4.160217	0.031009	0.0012	72.86473	4.967739	14.56643	4.893839	34.22683	0.073899
25699.83	3.615698	0.029688	0.001149	67.97052	8.713929	15.74718	8.16898	34.68153	0.544949
27677.91	2.745095	0.028597	0.001059	62.84338	14.03062	16.73187	11.1751	33.75221	2.855518
30153.84	1.67156	0.028283	0.001012	56.45497	21.9943	19.12198	15.41335	29.55171	6.58095
33827.49	1.009148	0.02845	0.000972	52.88456	27.32477	22.49177	20.92325	25.69689	6.401517
19839.22	5.808091	0.051402	0.001274	84.91413	0	26.11629	0	21.62894	0
20264.14	5.86748	0.047547	0.001275	83.54592	0	27.89042	0	21.09976	0
21062.33	5.56968	0.044497	0.001273	81.44833	0	24.11552	0	21.31592	0
22126.21	5.582822	0.043825	0.001291	81.42191	0	23.47307	0	23.68474	0
23268.13	5.638347	0.042439	0.001296	81.38495	0	21.68466	0	27.4042	0
24798.35	5.735097	0.040159	0.001282	80.89603	0	21.06472	0	30.28967	0
26471.39	5.824752	0.037694	0.001268	78.69988	0.146031	22.163	0.146031	31.94716	0
28050.73	5.872672	0.036582	0.001248	76.45218	0.836562	21.92088	0.836562	33.66615	0
30207.22	5.950092	0.034774	0.00121	74.12485	2.612119	19.85414	2.612119	32.84053	0
33171.12	6.075116	0.034085	0.001226	72.16074	6.034012	19.34467	6.034012	30.75165	0
36424.16	6.136377	0.032053	0.001239	68.52709	9.153972	18.57711	9.153972	28.10967	0
19838.2	5.807818	0.051402	0.001274	84.91335	0	26.11743	0	21.63006	0
20264.63	5.867533	0.047548	0.001275	83.54372	0	27.89135	0	21.09706	0
21183.1	5.552626	0.045373	0.00128	81.7412	0	24.76987	0	21.26279	0
22419.86	5.655726	0.045161	0.001327	81.90832	0	24.81446	0	23.23881	0
23734.19	5.872965	0.044781	0.001358	82.37675	0	24.11674	0	26.20092	0
25519.28	6.178531	0.044872	0.001384	82.44005	0	24.59447	0	28.63146	0
27547.46	6.542806	0.045349	0.001402	81.24721	0	26.95382	0	29.87575	0
29708.67	6.978726	0.045821	0.001423	79.96201	0	28.85674	0	30.53774	0
32869.23	7.88047	0.046392	0.001475	80.15825	0	30.36393	0	28.88606	0
36318.51	8.756085	0.046912	0.001565	79.16733	0	29.87672	0	26.97025	0
40110.3	9.486295	0.046741	0.001671	77.04949	0	27.53198	0	26.6225	0
19184.14	5.29564	0.053963	0.001379	85.0396	0	26.37726	0	22.02245	0
19726.91	5.726885	0.054685	0.001405	85.21006	0	27.31941	0	21.82338	0
21508.98	6.058537	0.055119	0.001428	85.20201	0	27.38981	0	21.99713	0
21806.47	5.671886	0.053819	0.001406	82.95487	0	25.53597	0	23.03391	0
18295.05	3.516482	0.037069	0.001062	73.76847	6.857961	15.44822	2.624503	22.86388	2.557044
18263.84	2.302962	0.029564	0.001042	67.56903	19.30582	14.82986	7.234551	21.23857	6.826259
18321.86	1.584402	0.028497	0.001024	62.5259	27.12858	15.69666	10.84654	19.77526	9.080469
17655.58	0.854042	0.026635	0.000984	51.90783	23.28397	12.32705	8.567382	17.02868	8.030078
17112.77	0.337406	0.02526	0.000953	42.83061	19.93126	9.784841	6.846585	14.49925	7.057151
16737.77	-0.05879	0.024183	0.000926	34.46482	16.35885	7.637264	5.356	11.89388	5.867964

16575.23	-0.30601	0.023315	0.000905	27.7071	13.17741	5.87592	4.109657	9.737147	4.815968
19184.14	5.29564	0.053963	0.001379	85.0396	0	26.37726	0	22.02245	0
19726.91	5.726885	0.054685	0.001405	85.21006	0	27.31941	0	21.82338	0
21508.98	6.058537	0.055119	0.001428	85.20201	0	27.38981	0	21.99713	0
22484.26	5.941663	0.054994	0.001441	83.86278	0	26.95446	0	22.44834	0
20380.37	4.647856	0.040322	0.001168	79.32864	1.03599	20.2833	1.03599	23.54479	0
19640.26	3.671928	0.034846	0.001148	73.91145	8.546376	18.03439	5.809357	22.88315	2.020872
19137.1	2.408691	0.031857	0.001095	66.30975	18.41341	17.09321	10.90403	20.84733	5.041243
18938.61	1.773248	0.031003	0.001082	63.04929	23.13655	16.42607	10.932	20.6529	7.581254
18766.97	1.371818	0.030175	0.001068	58.57635	24.77506	15.78538	10.80645	19.67947	8.367757
18537.32	0.939486	0.029026	0.001044	52.777	23.22236	14.49653	10.08583	18.05593	7.884467
18198.97	0.507272	0.027487	0.001009	45.24524	20.54332	12.23026	8.607551	15.77758	7.09157
19184.14	5.29564	0.053963	0.001379	85.0396	0	26.37726	0	22.02245	0
19726.91	5.726885	0.054685	0.001405	85.21006	0	27.31941	0	21.82338	0
21508.98	6.058537	0.055119	0.001428	85.20201	0	27.38981	0	21.99713	0
22544.62	5.967047	0.055144	0.001445	83.93117	0	27.11635	0	22.37521	0
21513.11	5.193186	0.044023	0.001251	81.19252	0.005021	23.5088	0.005021	23.24896	0
20910.01	4.708998	0.039479	0.001236	77.54395	0.684693	21.79544	0.684693	23.4154	0
20806.14	4.543861	0.039753	0.001245	74.45199	1.213232	21.73789	1.213232	23.59085	0
20416.7	3.915193	0.038165	0.001222	69.94522	4.753614	19.62189	4.380662	23.36761	0.276713
20288.94	3.228132	0.036911	0.001205	66.70903	11.08558	19.37957	8.934408	22.77771	1.582536
20639.9	2.77825	0.036484	0.001204	64.76013	15.89239	20.49102	12.99346	22.06522	2.114906
21024.55	2.476059	0.035933	0.001198	61.98057	17.89231	20.84782	13.64726	21.29614	3.069985
19184.14	5.29564	0.053963	0.001379	85.0396		26.37726		22.02245	
19773.65	5.750452	0.054781	0.00141	85.30583		27.44662		21.7937	
21997.14	6.300809	0.056657	0.001473	85.92308		28.78744		21.55174	
23647.66	6.459819	0.057566	0.001512	86.21695		30.66203		22.06415	
24409.68	6.468173	0.057658	0.001528	86.12363		32.41845		22.39153	
24750.82	6.427691	0.057732	0.001538	85.58797		34.56443		22.85705	
24888.5	6.427082	0.058125	0.001551	84.91492		36.61535		23.2095	
25224.58	6.457699	0.058881	0.001573	84.25636		38.83553		22.75033	
25590.42	6.496068	0.059728	0.001596	83.61074		40.89784		22.22343	
26131.92	6.604172	0.060508	0.001617	83.19504		42.79324		21.61762	
26748.31	6.752302	0.06134	0.001637	82.59891		44.66731		21.07545	

20488.2	5.187989	0.053407	0.001541	85.1679	0	28.16621	0	22.38295	0
22754.34	5.251368	0.051676	0.001452	82.94466	0.407539	29.79734	0.198568	22.76001	0.18347
22232.6	2.884498	0.041721	0.00132	69.79754	9.513335	17.8831	6.585928	24.73899	2.742137
22674.53	1.862288	0.040886	0.001333	61.62074	15.14187	13.50154	9.866574	24.49637	5.043157
22877.84	1.299005	0.03906	0.001358	54.05828	17.0859	11.57721	10.12095	22.41077	6.707612
23066.1	0.710857	0.038088	0.001413	44.43844	16.22068	9.345361	8.626708	20.21129	7.372408
22959.56	-0.013	0.036892	0.001477	33.02611	12.52284	6.149489	5.767473	16.23286	6.570567
22860.68	-1.12158	0.036011	0.00152	21.14913	7.136922	2.530756	2.305629	11.81148	4.681733
23338.34	-2.03066	0.035158	0.00153	12.57848	3.368281	0.766552	0.634568	8.034284	2.637252
24755.21	-2.96418	0.034654	0.001565	6.997691	1.10035	0.272789	0.199416	5.076864	0.864297

20488.2	5.187989	0.053407	0.001541	85.1679	0	28.16621	0	22.38295	0
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22754.34	5.251369	0.051676	0.001452	82.94466	0.407649	29.79734	0.198704	22.76001	0.183446
23610	4.240581	0.044708	0.001356	76.88717	3.532853	24.29469	2.36388	25.61965	1.096463
23641.2	3.205621	0.043851	0.001354	70.00959	7.961689	17.96216	5.49414	27.06623	2.361499
23184.88	2.180035	0.04163	0.001366	62.63533	12.12873	12.77888	8.057003	26.49068	3.917206
23123.77	1.57812	0.040571	0.001405	54.85176	14.15819	10.44079	8.654377	24.55648	5.298179
23116.14	1.081753	0.039542	0.001468	45.88167	13.45991	8.345629	7.543968	20.93093	5.71524
23117.59	0.29283	0.038654	0.001543	35.53197	11.27678	6.175552	5.760333	16.86461	5.331958
23070.58	-0.7586	0.037829	0.001603	24.12237	7.090664	3.064458	2.825814	12.71098	4.107217
23504.01	-1.71775	0.03714	0.001626	15.29399	3.46024	0.963457	0.823206	9.000526	2.528946
20488.2	5.187989	0.053407	0.001541	85.1679	0	28.16621	0	22.38295	0
22754.34	5.251369	0.051676	0.001452	82.94466	0.407675	29.79734	0.198748	22.76001	0.183442
24259.43	4.77699	0.046547	0.001392	79.36408	2.274973	26.67613	1.517279	26.00758	0.712028
24712.49	4.171506	0.046076	0.001385	74.68364	4.52467	22.64058	3.104565	27.39733	1.361214
24120.61	3.174383	0.044017	0.001391	68.55802	7.637978	16.92295	5.27734	27.82907	2.276974
23538.08	2.290649	0.042401	0.001415	61.05826	10.72878	12.04592	7.10213	27.03315	3.482716
23206.24	1.659046	0.041355	0.001467	53.35097	11.94797	9.107426	7.427101	23.951	4.341878
23333.02	1.154156	0.042301	0.001545	50.79413	10.95202	7.896986	6.572927	22.98411	4.267655
23462.36	1.040526	0.043132	0.001617	48.91236	10.23237	7.030749	6.02439	22.19275	4.084067
23514.39	0.827986	0.043598	0.001696	44.62521	8.861025	5.64103	5.001387	20.70993	3.729333
20488.2	5.187989	0.053407	0.001541	85.1679	0	28.16621	0	22.38295	0
22754.34	5.251369	0.051676	0.001452	82.94466	0.407317	29.79734	0.198699	22.76001	0.183257
25404.08	5.5846	0.053226	0.001576	82.22418	1.560337	30.74861	1.12735	25.90522	0.409222
26474.05	5.589399	0.053319	0.001592	80.22289	2.407086	29.6203	1.791991	27.23309	0.593407
26715.38	5.363204	0.052035	0.001591	78.08753	2.96015	28.01134	2.202958	27.60805	0.737041
26791.82	5.077342	0.051086	0.001598	75.41992	3.55109	26.8714	2.649644	27.08142	0.87535
26508.97	4.707403	0.050108	0.00161	72.80107	3.709385	24.77426	2.809326	25.78329	0.871732
25644.42	3.885973	0.048906	0.001626	68.4229	4.01721	19.60835	2.98106	25.35427	0.997391
24792.44	3.038293	0.048156	0.001667	63.31241	4.522271	13.89121	3.218944	25.24384	1.248392
24095.89	2.213554	0.047694	0.001723	57.38148	5.28675	8.1953	3.520533	25.24672	1.693463
19683.39	4.900711	0.052686	0.001525	85.37362	0	26.97306	0	21.42961	0
20488.2	5.187991	0.053407	0.001541	85.1679	0	28.16621	0	22.38295	0
23229.39	5.459494	0.054421	0.001534	83.95617	0	30.92279	0	23.04163	0
25819.2	5.941658	0.057901	0.001595	82.66634	0	32.69433	0	25.40636	0
27089.01	6.142927	0.059898	0.001646	80.91136	0	32.53356	0	26.45156	0
27495.24	6.085855	0.059753	0.001706	79.21625	0	31.78639	0	26.65812	0
27814.61	6.073504	0.06002	0.001772	77.26639	0	31.93169	0	25.9048	0
27803.36	5.901086	0.060713	0.001859	75.5775	0	31.18239	0	24.36699	0
27314.9	5.402866	0.06016	0.001953	73.06262	0	28.24774	0	23.64848	0
27050.43	5.055819	0.060379	0.002054	71.15732	0	26.00091	0	23.18901	0
27010.61	4.819476	0.060519	0.002171	69.81351	0	24.14769	0	23.27217	0
19839.46	5.42352	0.05136	0.001509	83.38356	0	26.3022	0	21.11063	0
20255.15	5.275602	0.053768	0.001491	83.3698	0	26.93455	0	22.31947	0
22797.51	5.256886	0.051612	0.001426	84.5918	0.001258	19.10294	0.000581	27.34753	0.000694
22007.72	4.689595	0.035677	0.001218	82.93371	0.29964	8.716502	0.000987	24.10281	0.298543
20445.76	2.634773	0.02833	0.001292	57.93048	1.715441	2.418755	0.001035	15.35489	1.713824

23118.49	0.146171	0.024071	0.001485	24.84594	1.80112	0.519748	0.000756	8.106443	1.79972
24831.52	-1.49494	0.021971	0.00146	8.723626	1.676218	0.198098	0.000495	4.712165	1.676218
28342.75	-1.92149	0.021142	0.001419	4.134894	1.018658	0.142658	0.000382	2.430177	1.018194
32395.01	-2.18659	0.02028	0.001486	2.202238	0.313291	0.118896	0.000335	0.943114	0.312977
36571.21	-2.49649	0.019381	0.001498	1.543162	0.11581	0.088768	0.00031	0.535597	0.115519
41129.98	-2.88949	0.018028	0.001523	1.100733	0.012665	0.069725	0.000293	0.236813	0.012372
19839.46	5.415825	0.051275	0.001508	83.38356	0	26.3022	0	21.11063	0
20255.15	5.270526	0.053881	0.001494	83.3698	0	26.93455	0	22.31947	0
22797.51	5.238513	0.051776	0.001425	84.5918	0.001258	19.10294	0.000581	27.34753	0.000694
24397.83	5.359405	0.042126	0.001299	86.76845	0.615069	8.549618	0.001979	31.00085	0.61309
24346.48	4.524572	0.033877	0.001187	81.28988	5.801765	2.663951	0.005295	32.05703	5.796334
26417.89	2.912376	0.029674	0.001222	61.29428	10.24635	0.717245	0.005699	27.09891	10.24023
28586.33	0.871263	0.026662	0.001384	38.25093	10.24098	0.397783	0.004684	20.68107	10.23645
30730.65	-0.4716	0.024701	0.001428	23.47157	8.142369	0.323749	0.003335	15.92561	8.139162
33634.85	-1.38411	0.021822	0.001437	12.31745	4.024574	0.302951	0.001491	9.227515	4.02256
37812.71	-2.10621	0.01994	0.001497	4.858349	1.545028	0.268762	0.000375	3.553471	1.545028
42975.55	-2.5731	0.018803	0.001566	2.439965	0.739614	0.230675	0.00028	1.418054	0.739351
19839.46	5.415825	0.051275	0.001508	83.38356	0	26.3022	0	21.11063	0
20255.15	5.270526	0.053881	0.001494	83.3698	0	26.93455	0	22.31947	0
22797.51	5.237003	0.051776	0.001425	84.5918	0.001258	19.10294	0.000581	27.34753	0.000694
24887.58	5.521972	0.047187	0.001331	87.52772	0.55571	10.24529	0.121203	33.25942	0.434451
25850.58	5.179375	0.039108	0.00124	87.54476	5.734015	5.250639	1.10243	38.32481	4.631714
28133.97	4.361923	0.034094	0.001081	81.60893	17.56244	5.116814	3.55507	38.51997	14.00621
30497.69	3.31286	0.030727	0.001116	67.68823	21.47402	5.40403	4.724284	34.59173	16.75504
32369.66	1.833916	0.028189	0.00124	49.91375	18.83308	4.479959	4.023338	29.14257	14.80467
34959.38	0.335145	0.025187	0.001335	31.37597	11.93798	2.888566	2.502907	19.89341	9.439922
38451.2	-1.08993	0.022253	0.001461	16.03321	4.75	1.131919	0.712454	10.39668	4.0369
42561.24	-1.84408	0.019862	0.001465	9.99115	2.290265	0.477788	0.043628	6.479646	2.246018
19839.46	5.415825	0.051275	0.001508	83.38356	0	26.3022	0	21.11063	0
20255.15	5.270526	0.053881	0.001494	83.3698	0	26.93455	0	22.31947	0
22797.51	5.236026	0.051776	0.001425	84.5918	0.001258	19.10294	0.000581	27.34753	0.000694
25087.62	5.579103	0.047525	0.001339	87.42095	0.469068	10.89634	0.226973	32.93924	0.242095
26620.8	5.47452	0.042318	0.001271	87.83062	4.398361	7.481684	2.089904	37.65057	2.308456
29807.95	5.038393	0.036284	0.001146	83.86922	14.77297	9.493808	7.072561	37.54073	7.701499
33149.66	4.32779	0.033092	0.001109	75.41463	22.83902	12.3122	11.24878	34.33171	11.59024
35670.68	3.485563	0.03142	0.001152	65.48803	24.09761	12.90976	12.22836	32.35727	11.86924
38685.67	2.88414	0.029471	0.001186	55.79685	21.04203	11.36602	10.79685	28.59895	10.24518
41501.76	2.192097	0.026867	0.001209	46.22222	17.4188	9.410256	8.854701	23.45299	8.564103
45951.07	2.150599	0.023952	0.001197	42.86066	15.70492	8.803279	8.278689	21.83607	7.430328
19839.46	5.415825	0.051275	0.001508	83.38356	0	26.3022	0	21.11063	0
20255.15	5.270526	0.053881	0.001494	83.3698	0	26.93455	0	22.31947	0
22797.51	5.238395	0.051776	0.001425	84.5918	0.001258	19.10294	0.000581	27.34753	0.000694
26029.19	5.939408	0.051526	0.001378	88.33974	0.246323	13.95256	0.232013	32.18497	0.014284
29027.35	6.487295	0.050342	0.00135	90.43389	2.550962	13.16479	2.443913	37.28505	0.107243
33220.68	6.780857	0.046985	0.001228	90.09747	10.50682	17.53411	10.01949	38.09942	0.487524
37839.13	6.86224	0.042571	0.001178	87.69231	21.10256	24.29915	19.60684	35.58974	1.497436
40893.18	6.538844	0.038512	0.001149	82.97189	26.45783	26.21687	23.62249	34.36948	2.838554

43224.97	6.163431	0.03382	0.001138	76.44201	26.5674	24.05956	22.75862	31.7163	3.806426
45403.63	5.642486	0.030155	0.001102	68.88281	25.28125	22.17969	21.46094	28.20313	3.81875
49566.89	5.5551	0.027327	0.001067	63.33587	23.35106	21.35258	20.6079	26.13222	2.74772
19839.46	5.423465	0.05136	0.001509	83.38356	0	26.3022	0	21.11063	0
20255.15	5.275765	0.053768	0.001491	83.3698	0	26.93455	0	22.31947	0
23054.99	5.907096	0.053987	0.001588	84.81174	0	21.8411	0	24.93618	0
27232.87	7.043264	0.059243	0.0016	89.31104	0	20.74468	0	27.63425	0
32247.11	8.31389	0.067889	0.001616	92.56791	0	23.94669	0	32.14762	0
37883.23	9.842227	0.073512	0.001552	93.50427	0	30.20513	0	32.35043	0
44760.13	11.79434	0.075045	0.001575	93.49711	0	38.38873	0	30.43353	0
51765.18	13.8938	0.076389	0.001594	92.8934	0	44.66371	0	29.41624	0
58807.64	15.7926	0.075702	0.001644	91.30184	0	47.78226	0	27.54032	0
63671.5	16.65145	0.074419	0.001689	88.07799	0	48.8468	0	25.6546	0
68700.62	17.09799	0.073224	0.001725	83.88158	0	48.69518	0	24.47917	0

Primary energy (% oil)	Primary energy (% oil CCS)	Primary energy (% nuclear)	Primary energy (% solar)	Primary energy (% wind)	Primary energy (% geothermal)	Primary energy (% hydro)	Primary energy (% biomass)	Primary energy (% biomass CCS)	Primary energy (% trad biomass)
38.08227	0	2.170833	0.003586	0.081466		2.299237	9.55969	0	8.27698
33.94522	0	1.961452	0.024	0.242912		2.448657	10.42106	0	8.017288
32.05327	0.044818	2.125988	0.373569	0.949272		3.278688	8.93334	0.10504	4.434956
21.83565	0.260438	2.726493	0.811625	1.434764		4.480825	18.71338	2.742614	2.706408
10.90966	0.478369	2.006716	6.551799	4.121152		5.35785	26.49344	9.635962	2.337256
7.814271	0.340982	0.849163	11.15775	7.078476		4.579424	28.65817	10.68169	1.912884
6.181001	0.129036	0.67855	14.35862	6.806388		4.071601	31.30639	12.10618	1.423615
5.213311	0.123654	0.698525	16.10635	4.98096		4.174564	34.73574	14.73821	0.988238
4.595394	0.137059	0.8432	17.78888	5.003167		4.369516	40.16283	19.49902	0.738612
4.280803	0.129261	1.063713	18.865	6.020765		4.497867	45.15952	25.15639	0.534228
4.026545	0.088916	0.998814	18.61046	5.554478		4.450078	51.80702	33.14769	0.328312
38.08227	0	2.170833	0.003586	0.081466		2.299237	9.55969	0	8.27698
33.94522	0	1.961452	0.024	0.242912		2.448657	10.42106	0	8.017289
31.42775	1.85E-17	1.929664	0.293204	0.80466		3.012323	7.281276	0	4.241955
26.78006	0.004253	1.977614	1.016873	1.663069		3.478409	8.005654	0.034091	2.508006
22.05637	0.092436	1.537974	3.796802	2.925597		3.904536	11.79922	1.140104	2.260969
19.93039	0.103133	0.707179	8.591632	4.406111		4.061698	15.29719	3.101071	1.875653
17.39183	0.055289	0.494351	12.42319	5.122616		4.046274	20.6858	6.484656	1.427011
14.72489	0.011531	0.372206	15.57107	5.360615		3.997869	26.25636	10.59521	1.076121
9.602381	0.007814	0.36216	17.14308	5.293344		3.991607	35.33962	18.15047	0.79902
6.768699	0.003346	0.435338	17.03513	4.583927		4.274131	42.09906	24.74271	0.554606
6.549971	0.004123	0.448553	20.40479	4.736437		4.451006	40.14312	23.19541	0.351506
38.08227	0	2.170833	0.003586	0.081466		2.299237	9.55969	0	8.27698
33.94451	0	1.961411	0.024	0.242907		2.448606	10.42294	0	8.017121
31.23642	8.18E-22	1.884552	0.283642	0.778678		2.953254	7.226259	5.06E-26	4.190125
25.90727	1.67E-09	1.766298	0.739103	1.364912		3.170844	7.708915	4.60E-26	2.47751
21.31696	1.07E-07	1.216691	2.277078	2.474081		3.380478	10.05848	6.89E-05	2.222137
19.82236	3.06E-07	0.514846	5.860486	3.968358		3.399821	11.27845	0.002727	1.858127
18.09172	0.00057	0.330826	9.800124	4.424375		3.46468	13.06478	0.135451	1.457988
16.00223	0.001203	0.209757	14.45645	5.106993		3.693856	16.79531	1.174223	1.13577
11.76479	0.001317	0.139486	17.66186	5.826825		3.942314	24.68318	5.379058	0.863194
7.295873	0.002411	0.168117	18.02758	5.599717		4.14498	37.42763	15.58775	0.583309
5.674801	0.002768	0.203011	18.74792	5.067254		4.253577	42.52323	21.17006	0.341319
38.08227	0	2.170833	0.003586	0.081466		2.299237	9.55969	0	8.27698
33.94452	0	1.961412	0.024	0.242907		2.448607	10.42293	0	8.017123
31.19624	3.21E-21	1.8842	0.283084	0.777639		2.951752	7.314605	6.92E-22	4.188355
25.65717	9.49E-06	1.729944	0.688459	1.289664		3.11479	7.503848	9.49E-06	2.474407

20.68332	8.59E-06	1.121212	1.790208	2.178823	3.178537	9.704668	8.59E-06	2.198924	
18.95698	5.25E-06	0.433074	4.27687	3.394615	3.077119	10.89243	5.21E-06	1.809548	
17.41009	2.44E-07	0.251102	7.056314	3.857251	3.087111	11.82362	3.70E-13	1.420342	
15.54181	5.57E-07	0.128566	11.45208	4.170055	3.262427	14.18387	0	1.114457	
12.26718	1.78E-05	0.049374	15.60445	5.030383	3.544052	18.24237	0.16867	0.892652	
9.325088	0.003201	0.068863	18.23662	5.801074	3.905409	22.71285	1.268353	0.654595	
7.425195	0.002909	0.08107	19.86912	5.922335	4.275952	27.08599	3.57419	0.399924	
38.08227	0	2.170833	0.003586	0.081466	2.299237	9.55969	0	8.27698	
33.94452	0	1.961412	0.024	0.242907	2.448607	10.42293	0	8.017123	
31.20331	0	1.883803	0.282789	0.776986	2.950988	7.32542	0	4.187171	
25.54727	0	1.723789	0.676695	1.269546	3.103955	7.886172	0	2.462735	
20.47837	0	1.098653	1.689189	2.107853	3.127798	9.81648	0	2.186689	
18.89413	0	0.418245	3.93447	3.256509	3.019696	10.42633	0	1.801629	
17.23087	0	0.232682	6.229177	3.601585	2.966081	11.23107	0	1.400886	
15.14083	0	0.106117	9.495554	3.717714	3.011656	13.19767	0	1.084367	
11.95755	0	0.026402	13.33495	4.202801	3.167478	16.34285	0	0.872257	
9.332095	0	0.024927	15.73899	4.440737	3.396636	18.57493	0	0.640093	
7.739392	0	0.018294	16.82034	4.538718	3.75146	19.60329	0	0.399827	
37.1603		2.145889	0.066319	0.082468	0.077085	2.283694	10.43273	0	6.313469
34.6137		1.979246	0.495561	0.331374	0.109391	2.574799	10.78776	0	6.100142
36.25804		2.163166	1.81131	1.163108	0.1058	2.673548	10.85672	0	4.928419
33.03002		3.856933	5.200909	4.637629	0.258661	4.221062	14.39839	0.188153	5.140015
19.471		6.389369	8.64211	9.795315	0.667645	5.479725	17.65932	1.069871	4.384678
6.092513		10.81057	11.63746	12.98664	0.964196	5.636602	21.67605	3.618373	3.276749
2.278912		16.13354	13.32718	15.09036	1.224668	5.587959	25.04442	7.809569	2.161494
1.59883		18.18411	15.35451	18.10632	1.387719	5.510832	27.03789	15.33364	1.241363
1.14318		17.59508	16.82674	21.23927	1.415578	5.297676	27.99792	21.12146	0.388151
0.638776		14.76196	19.17322	23.8167	1.418308	5.038889	28.49376	21.64451	0
0.354858		9.908487	22.55887	26.56851	1.422923	4.729076	28.11109	21.31132	0
37.16881		2.145708	0.066313	0.083322	0.077078	2.283072	10.43185	0	6.312938
34.55573		1.97552	0.494828	0.331549	0.109186	2.569354	10.97604	0	6.08866
36.12345		2.199768	1.852565	1.162165	0.105921	2.676237	11.16208	0	4.934017
34.92815		3.095242	3.766538	2.860195	0.093713	3.281307	11.87584	0.145586	4.451092
30.97194		4.247915	5.831626	4.584094	0.086349	3.505541	12.22775	0.578732	3.632962
21.39871		6.568894	7.530661	6.176945	0.123933	4.032362	13.22415	1.722787	2.729923
13.28154		9.440858	8.85876	7.642731	0.171336	4.064544	14.30136	4.644696	1.818827
5.273943		12.12454	10.67283	9.386063	0.263691	4.206149	16.41603	10.32303	1.033692
1.610703		13.3728	12.44436	12.88995	0.496193	4.268242	18.83825	14.29835	0.324748
0.597582		13.44126	14.47229	17.60157	0.721082	4.260131	20.93494	16.06436	0
0.257258		12.03509	17.02242	22.61175	0.92421	4.085852	22.20367	16.97384	0
37.16881		2.145708	0.066313	0.083322	0.077078	2.283072	10.43185	0	6.312938
34.55484		1.975469	0.494815	0.33154	0.109183	2.569287	10.97855	0	6.088502
36.13187		2.197578	1.822875	1.15422	0.105815	2.659127	10.91462	0	4.929106
35.34476		2.06784	3.375006	2.106263	0.08653	2.724201	10.0523	0.046203	4.155201
33.37892		2.272131	5.110403	3.558816	0.020617	3.171846	9.798535	0.24562	3.33233
28.43113		3.229936	6.382207	5.001338	0.044558	3.166755	10.49543	0.884253	2.485626
20.83505		5.518461	7.68696	6.414187	0.074449	3.500935	11.29892	2.756701	1.697675

14.81782	9.054554	8.522221	7.242783	0.103981	3.580994	11.61534	6.550655	0.967027
8.431461	11.45038	9.250169	8.234528	0.164093	3.563697	12.49095	9.313983	0.296739
3.846166	12.58736	10.80778	11.08737	0.267421	3.680703	14.3823	10.8751	0
1.785957	12.98019	12.29359	14.60132	0.444176	3.592446	16.162	12.33581	0
37.16881	2.145708	0.066313	0.083322	0.077078	2.283072	10.43185	0	6.312938
34.55484	1.975469	0.494815	0.33154	0.109183	2.569287	10.97855	0	6.088502
36.02393	2.191051	1.803722	1.040515	0.105509	2.65144	10.85166	0	4.914855
34.59844	1.896104	3.215046	2.025035	0.083161	2.623144	9.585094	0.014119	4.060458
33.03554	1.642887	4.677738	3.093126	0.018388	2.927352	8.701292	0.07242	3.177852
29.95579	2.166489	5.739752	4.172609	0.016854	2.827028	8.623175	0.273809	2.335993
24.07147	3.232798	6.521202	5.766095	0.014659	2.806241	8.799485	0.793995	1.585685
17.54181	5.674192	7.496251	6.767976	0.009715	2.930473	9.158872	2.133165	0.924753
12.3593	9.177964	8.104397	7.265963	0.018136	3.160529	9.446062	4.51617	0.288229
7.781287	13.02224	9.270311	7.814636	0.067095	3.413565	9.9758	6.729375	0
4.695907	14.01544	9.736554	9.462634	0.128096	3.243578	10.54813	7.970213	0
37.16889	2.145713	0.066313	0.083322	0.077079	2.283077	10.43188	0	6.312952
34.55573	1.97552	0.494828	0.331549	0.109186	2.569154	10.97604	0	6.08866
36.0169	2.17893	1.801018	1.01695	0.105351	2.607959	10.84267	0	4.907489
34.26409	1.721007	3.149203	1.775254	0.078711	2.537901	9.320122	0	3.976726
32.29609	1.052775	4.335817	2.54193	0.016167	2.763788	7.910958	0	3.052353
29.54165	0.769886	4.98581	3.506022	0.014538	2.578543	7.254665	0	2.201229
24.58972	1.193515	5.670036	4.728328	0.012523	2.466531	7.234218	0	1.463545
20.86515	2.028838	6.248403	5.951957	0.00377	2.443088	6.878573	0	0.84725
21.43018	3.723261	6.798038	6.859817	0.004888	2.372432	6.124725	0.002933	0.264095
22.06441	5.244559	7.385874	7.281717	0.004615	2.293612	5.636843	0.031039	0
21.8403	7.820124	7.830678	7.127195	0.004475	2.790374	5.917293	0.118626	0
37.16586	2.145824	0.066317	0.083327	0.077083	2.282979	10.43242	0	6.313278
34.5553	1.975473	0.494816	0.331541	0.109183	2.569093	10.97857	0	6.088514
35.70854	2.057451	1.790751	0.948267	0.10475	2.6322	10.72659	0	4.879511
33.85505	1.671473	3.076314	1.538307	0.07693	2.534652	9.19805	0	3.92464
32.05909	0.966039	4.145056	2.220171	0.014252	2.528909	7.755615	0	2.992416
29.21411	0.512251	4.737523	2.922147	0.012702	2.318724	7.062539	0	2.139044
24.41764	0.607293	5.269435	3.86123	0.011497	2.184298	6.823877	0	1.406376
20.56754	0.974369	5.628203	4.833383	0.003263	2.189487	6.415905	0	0.799968
20.90827	1.561241	5.592313	5.054741	0.002965	2.134388	5.504095	0	0.242706
22.32036	2.488094	5.698301	5.640777	0.002727	2.039636	4.968998	0	0
22.895	3.475857	6.053499	6.479566	0.000767	1.911514	5.034295	0	0
36.63988	0	2.202857	0.002275	0.082024	0.046154	2.325435	10.29389	0
36.06729	0	2.075173	0.019158	0.092209	0.044109	2.445194	10.10706	0
35.81507	0	2.208578	0.035433	0.18587	0.042647	2.576661	9.742406	0
34.38499	0	2.942711	0.159141	0.676525	0.043881	2.830203	10.3864	0
35.45639	1.676398	3.707183	0.763785	1.890929	0.055191	4.196243	15.61084	0.753797
31.50062	5.245027	2.985554	1.482161	2.661319	0.056974	4.156616	21.08115	5.171067
27.054	7.20158	2.294864	2.075887	3.709791	0.058096	4.041289	25.28726	10.47234
22.5521	6.686528	2.21028	2.957838	5.58765	0.061815	4.362538	32.90513	16.29116
18.54652	6.027525	2.218388	4.285147	7.668911	0.065119	4.436231	38.48879	20.3909
14.93367	5.134887	2.167541	5.77291	10.15704	0.067892	4.348389	43.01482	23.6881

12.09403	4.251798	2.036974	7.411216	12.5058	0.070154	4.221999	46.04045	25.80002
36.63988	0	2.202857	0.002275	0.082024	0.046154	2.325435	10.29389	0
36.06729	0	2.075173	0.019158	0.092209	0.044109	2.445194	10.10706	0
35.81507	0	2.208578	0.035433	0.18587	0.042647	2.576661	9.742406	0
34.45997	0	2.854003	0.11698	0.470867	0.041862	2.743553	9.904164	0
35.50052	0	3.257766	0.389313	1.007133	0.047777	3.503497	12.46002	0
32.99391	0.716147	2.949585	0.836399	1.558342	0.051178	3.758798	16.9284	0.494917
28.36923	2.468151	2.60561	1.381542	2.471418	0.053836	3.885025	23.28702	5.314268
25.97032	4.623291	2.208264	1.762917	3.215005	0.055886	3.909979	25.79297	11.00117
23.11149	5.600855	1.973458	2.217705	4.189178	0.057725	3.891735	29.08841	13.38544
20.22454	5.252059	1.846906	2.946433	5.573741	0.059708	3.87243	32.91855	16.22344
17.23739	4.844199	1.865052	4.051757	7.429284	0.062359	3.845304	37.49596	19.55806
36.63988	0	2.202857	0.002275	0.082024	0.046154	2.325435	10.29389	0
36.06729	0	2.075173	0.019158	0.092209	0.044109	2.445194	10.10706	0
35.81507	0	2.208578	0.035433	0.18587	0.042647	2.576661	9.742406	0
34.43961	0	2.846362	0.114453	0.458651	0.041561	2.73612	9.865969	0
34.43476	0	2.922874	0.310944	0.818487	0.044439	3.119416	11.58598	0
32.33311	0	2.400829	0.603162	1.140964	0.046856	3.332102	14.92711	0
29.12325	0	1.821092	0.818669	1.481716	0.048293	3.244641	18.12869	0
26.95573	0.09624	1.591599	1.06681	1.931326	0.050629	3.371909	22.03767	0
24.55175	0.56862	1.428165	1.388939	2.524026	0.05223	3.389031	24.50393	0.607893
22.20388	0.78403	1.203517	1.658929	3.066811	0.05255	3.266407	25.98735	2.588474
19.83661	1.175056	1.043042	1.939088	3.690821	0.052984	3.109663	28.17982	5.038051
36.63988		2.202857	0.002275	0.082024	0.046154	2.325435	10.29389	
36.06551		2.033206	0.01899	0.092236	0.044004	2.415237	10.08347	
35.58391		1.994734	0.025099	0.09759	0.042209	2.400055	9.511012	
33.49077		1.92685	0.036077	0.108024	0.041237	2.290449	9.374646	
31.31365		1.694665	0.052208	0.122659	0.041747	2.370223	9.589364	
28.16649		1.373972	0.072508	0.134072	0.042459	2.643684	10.14005	
25.09007		1.106088	0.090148	0.168717	0.043295	2.764819	10.90694	
22.6705		0.907373	0.108949	0.206389	0.043891	2.698555	11.77363	
20.48947		0.755262	0.137506	0.26166	0.044302	2.633182	12.55278	
18.78419		0.629862	0.166881	0.318606	0.04437	2.52305	13.11796	
16.85614		0.541752	0.201121	0.386006	0.044493	2.383732	13.84008	

34.61874	0	1.950883	0.023692	0.241865	0.048194	2.436173	10.13129	0	6.009969
30.38731	0.025501	2.320997	0.281131	0.918903	0.270713	2.084119	11.17948	0.147866	5.471741
27.17544	0.18527	6.569746	0.878438	2.804766	0.635963	2.067305	17.24625	3.277994	6.029965
23.62283	0.232138	9.57163	1.775909	3.991367	0.719687	2.041785	20.27889	7.010207	5.909532
20.07029	0.257335	11.8831	3.019368	4.719397	0.748274	2.10461	23.46697	11.52662	5.851595
14.88179	0.221568	14.23383	4.547075	4.667742	0.749597	2.195827	29.16749	17.53336	5.827096
10.64376	0.184798	16.63157	6.242994	5.071084	0.753959	2.342614	35.93168	23.7552	5.854966
6.806895	0.149559	18.8747	8.050088	5.787689	0.749801	2.512982	42.87562	29.84122	5.844396
3.777648	0.096461	18.35949	10.40007	6.815487	0.734905	2.637415	48.47415	34.91536	5.523339
1.648038	0.036638	16.77153	11.99024	6.980887	0.550277	2.590816	54.11856	40.4596	4.705944
34.61874	0	1.950883	0.023692	0.241865	0.048194	2.436173	10.13129	0	6.009969

30.38731	0.025499	2.320997	0.281131	0.918903	0.270713	2.084119	11.17948	0.147889	5.471741
26.97283	0.07251	4.079025	0.656094	1.863145	0.501712	1.946699	14.06616	1.17692	5.477832
24.98121	0.10605	7.024248	1.414469	3.036501	0.618815	1.958299	15.93808	2.660985	5.427414
23.36577	0.154521	10.04477	2.590801	4.002103	0.687015	2.076739	17.96324	4.898381	5.499399
19.8545	0.205632	12.24219	4.086304	4.469985	0.71339	2.190398	21.44597	9.122779	5.50972
16.60512	0.200703	14.48924	5.745031	4.64677	0.713216	2.326956	26.19711	14.80196	5.492453
12.49181	0.184488	16.35135	7.268441	4.95625	0.694845	2.485056	32.71209	21.13357	5.467128
8.34693	0.157633	17.58962	9.311138	5.849771	0.681376	2.668024	39.7777	27.5332	5.345361
5.330007	0.108088	17.30784	11.7853	6.7466	0.64041	2.728735	45.49713	32.82111	5.002882
34.61874	0	1.950883	0.023692	0.241865	0.048194	2.436173	10.13129	0	6.009969
30.38731	0.025485	2.320997	0.281131	0.918903	0.270713	2.084119	11.17948	0.147894	5.471741
26.68038	0.045666	3.358351	0.57842	1.57171	0.44879	1.894585	12.78406	0.761421	5.22041
24.64572	0.058891	5.212477	1.168834	2.370631	0.534336	1.873406	14.15668	1.512256	5.063052
23.806	0.083664	7.871025	2.16628	3.211891	0.606057	1.996174	15.59056	2.594585	5.134421
21.97919	0.14393	10.52698	3.64173	4.048991	0.668331	2.151843	17.90387	4.81775	5.236871
20.29254	0.17899	12.90515	5.349308	4.511534	0.6926	2.317991	20.87245	8.520211	5.283553
19.91303	0.111438	13.82544	6.339686	4.222206	0.629738	2.450453	21.73835	9.870314	5.049272
19.68886	0.123915	14.38524	7.30805	4.150461	0.577281	2.623473	22.04313	10.73277	4.627802
18.27425	0.130304	14.61555	8.966803	4.646426	0.551227	2.72753	23.86725	13.12357	4.300479
34.61874	0	1.950883	0.023692	0.241865	0.048194	2.436173	10.13129	0	6.009969
30.38731	0.025361	2.320997	0.281131	0.918903	0.270713	2.084119	11.17948	0.147819	5.471741
25.57036	0.023765	2.733752	0.479883	1.304937	0.386456	1.809219	11.06157	0.435791	4.795671
23.3695	0.021688	3.541714	0.875718	1.707244	0.426883	1.748751	11.4768	0.660796	4.493194
22.46814	0.020151	4.389102	1.436745	1.855379	0.43295	1.802293	11.996	0.828227	4.330863
21.46709	0.026097	5.202047	2.194025	2.081729	0.438474	1.890512	12.7733	1.093051	4.179877
22.24352	0.028328	6.198394	3.073309	2.272574	0.449668	2.029194	13.17579	1.306286	4.080032
23.46027	0.038759	7.763816	4.289524	2.917497	0.495541	2.240195	13.87053	1.632046	4.043143
24.17736	0.054934	9.485336	5.907123	3.719986	0.52516	2.482727	14.56726	2.183162	3.936791
23.93946	0.072754	11.09397	8.156247	4.583334	0.532766	2.661708	15.59049	3.303304	3.813734
36.97095	0	2.161235	0.003546	0.081187	0.045444	2.290318	10.04465	0	6.19849
34.61874	0	1.950883	0.023692	0.241865	0.048194	2.436173	10.13129	0	6.009969
29.99176	0	2.144503	0.257116	0.81439	0.25588	2.041498	10.53044	0	5.308898
24.56564	0	2.582107	0.457054	1.223404	0.369127	1.780131	10.92184	0	4.680989
21.92623	0	3.270516	0.81848	1.57693	0.40293	1.709052	11.31073	0	4.343355
20.77174	0	3.95582	1.314716	1.70424	0.402761	1.751174	11.65504	0	4.11144
19.4299	0	4.558848	1.960992	1.81855	0.398637	1.820995	12.17559	0	3.903855
20.02812	0	5.240238	2.658915	1.882987	0.392845	1.934725	12.31279	0	3.731981
21.1664	0	6.190975	3.490713	2.251721	0.411113	2.103192	12.48966	0	3.549225
21.9674	0	6.793447	4.336342	2.587897	0.410944	2.275486	12.43857	0	3.322954
22.39366	0	7.032665	5.246242	2.876715	0.395502	2.374482	12.26088	0	3.089674
35.98795		2.178218	0.001334	0.082867	0.047202	2.300904	12.01679	0	7.117951
34.11577		2.027054	0.047066	0.346529	0.065208	2.25184	11.90173	0	6.72966
38.14134		1.961923	0.266376	0.771539	0.065537	1.736044	10.61633	0.000549	3.736689
50.11754		3.284752	0.52578	1.67842	0.206551	2.079611	9.288513	1.551951	1.643943
40.16168		6.637025	2.942603	4.239289	0.843169	4.443007	22.95877	18.51253	0.471302

16.21849	8.110644	9.114846	6.759104	2.219888	5.521008	43.43137	41.45658	0
3.813493	8.735348	17.13988	8.990623	3.668924	5.631675	47.10862	46.14483	0
1.562174	8.342798	22.62139	9.939738	4.4814	5.174412	45.31232	43.60876	0
1.140855	7.409809	26.82213	10.58245	4.585381	4.793475	43.60556	41.12726	0
0.919108	6.515034	30.64985	11.33851	4.364694	4.548982	41.05723	38.5936	0
0.794231	5.740842	33.91026	11.32784	4.211538	4.361722	39.32234	36.95055	0
35.98795	2.178218	0.001334	0.082867	0.047202	2.300904	12.01679	0	7.117951
34.11577	2.027054	0.047066	0.346529	0.065208	2.25184	11.90173	0	6.72966
38.14134	1.961923	0.266376	0.771539	0.065537	1.736044	10.61633	0.000549	3.736689
47.21515	2.430025	0.262228	1.148996	0.117656	1.612949	7.66186	0.392282	1.482895
46.55804	3.970129	0.688527	2.215886	0.227699	2.441276	9.171758	4.837746	0.395791
33.47224	5.85611	2.809168	3.881603	0.604976	3.70266	21.86542	19.56122	0
17.17389	7.138817	7.677339	5.638647	1.559	4.381717	35.35468	34.17807	0
7.219966	7.791791	14.45062	7.394186	2.87516	4.609876	39.40787	38.71313	0
2.783765	7.669453	21.69403	8.970692	3.993353	4.472757	40.89032	39.95367	0
1.036585	6.622889	27.41088	10.37523	4.689493	4.226079	41.81051	38.48968	0
0.791762	5.528484	30.90272	10.50833	4.80894	3.995618	41.80543	36.56442	0
35.98795	2.178218	0.001334	0.082867	0.047202	2.300904	12.01679	0	7.117951
34.11577	2.027054	0.047066	0.346529	0.065208	2.25184	11.90173	0	6.72966
38.14134	1.961923	0.266376	0.771539	0.065537	1.736044	10.61633	0.000549	3.736689
44.02716	2.152162	0.222145	0.993348	0.106652	1.49806	7.490299	0.126441	1.453714
43.96419	2.845269	0.277494	1.519182	0.152685	1.85422	5.808184	1.323529	0.372762
37.96755	3.936011	1.012084	2.633214	0.311658	2.706871	7.79146	5.185867	0
27.68823	5.136797	3.814422	4.00106	0.801591	3.535525	15.02651	13.5631	0
16.2963	6.307458	9.14967	5.595129	1.749366	4.016235	23.26738	22.43531	0
8.593992	7.060078	16.37597	7.420543	2.843023	4.188953	30.75581	30.23256	0
4.499077	6.829336	23.15498	9.243542	4.04059	4.091328	36.61439	36.19004	0
3.032743	5.906195	28.20354	9.884956	4.90885	3.967257	37.17699	36.80531	0
35.98795	2.178218	0.001334	0.082867	0.047202	2.300904	12.01679	0	7.117951
34.11577	2.027054	0.047066	0.346529	0.065208	2.25184	11.90173	0	6.72966
38.14134	1.961923	0.266376	0.771539	0.065537	1.736044	10.61633	0.000549	3.736689
43.57987	2.103382	0.215975	0.981166	0.103932	1.470993	7.711026	0.108716	1.442123
42.69216	2.658637	0.191481	1.394511	0.13051	1.712405	6.083447	1.073637	0.361977
36.83467	3.58136	0.478927	2.193135	0.175755	2.338692	7.366935	4.004997	0
28.76098	4.626341	2.053659	3.129756	0.344878	3.002927	11.43415	9.149268	0
20.21179	5.437385	5.38674	4.289134	0.715378	3.349908	15.29466	13.7477	0
15.82312	5.864273	10.24518	5.630473	1.238179	3.553415	17.662	16.61121	0
13.35897	5.82906	15.39316	7.187179	1.964957	3.673504	19.76923	19.04274	0
12.22131	5.152459	18.7541	7.741803	2.391803	3.59918	19.4918	18.98361	0
35.98795	2.178218	0.001334	0.082867	0.047202	2.300904	12.01679	0	7.117951
34.11577	2.027054	0.047066	0.346529	0.065208	2.25184	11.90173	0	6.72966
38.14134	1.961923	0.266376	0.771539	0.065537	1.736044	10.61633	0.000549	3.736689
42.2022	1.824566	0.206837	0.857957	0.092275	1.356831	7.324765	0.018153	1.389956
39.97267	1.817561	0.133698	0.935429	0.105056	1.291425	5.281859	0.145883	0.331967
34.47368	2.165692	0.103411	1.28655	0.104971	1.573099	4.703704	0.495127	0
27.80342	3.011111	0.598205	1.8	0.099487	2.102564	4.68547	1.016239	0
22.38554	4.412851	2.211245	2.804819	0.108755	2.53494	4.970281	1.694779	0

20.66614	5.876959	5.131661	4.163009	0.169906	2.846395	5.36442	2.581505	0
18.5	6.423437	9.335938	5.714844	0.357969	3.171094	6.128906	3.807813	0
15.84347	5.775076	13.48784	6.357143	0.572948	3.332827	7.105623	4.958967	0
35.98795	2.178218	0.001334	0.082867	0.047202	2.300904	12.01679	0	7.117951
34.11577	2.027054	0.047066	0.346529	0.065208	2.25184	11.90173	0	6.72966
38.03446	1.935227	0.263401	0.720166	0.057642	1.686343	10.5217	0	3.694959
40.93212	1.557751	0.197695	0.660208	0.063576	1.204407	7.006079	0	1.328521
36.4736	1.100974	0.115633	0.516146	0.067289	0.908457	4.722706	0	0.298821
30.96581	0.751624	0.013385	0.728462	0.075838	0.847778	4.079487	0	0
24.70376	0.449061	0.026908	1.090318	0.073627	1.011561	3.833092	0	0
18.83883	0.325888	0.180711	1.490482	0.078617	1.319162	3.68401	0	0
16.0023	0.55674	0.765553	1.967166	0.115265	1.628456	3.631912	0	0
13.59331	1.072423	2.233426	2.722563	0.230251	1.82507	3.837883	0	0
10.73465	1.804276	4.434759	3.411732	0.37648	1.973136	4.10636	0	0

Electricity use	Electricity per capita	Final heat energy	Final heat per capita	Final transport energy	Final transport per capita	Final industry energy	Final industry per capita	Economic consumpti on per capita	Secondary electricity
1.49E+13	2275.245	3.68E+12	563.5787	2.51E+13	3840.317	2.88E+13	4410.545	5287.719	18163.79
1.76E+13	2542.709	4.08E+12	589.978	2.48E+13	3587.43	3.38E+13	4884.978	5842.846	21268.47
2.05E+13	2702.585	3.24E+12	428.0241	2.6E+13	3433.458	3.28E+13	4328.749	8017.064	24145.1
1.95E+13	2424.081	2.03E+12	251.9005	1.73E+13	2147.409	2.99E+13	3710.446	11685.99	22576.69
2.31E+13	2758.613	1.57E+12	186.9968	1.83E+13	2180.069	3.12E+13	3724.41	16318.04	27477.11
3.06E+13	3591.944	1.4E+12	164.3437	1.98E+13	2324.468	3.37E+13	3953.894	21221.87	35266.97
3.8E+13	4468.973	1.14E+12	134.4765	2.03E+13	2392.594	3.55E+13	4175.651	26007.33	42485.01
4.35E+13	5242.284	8.69E+11	104.7354	2.14E+13	2576.279	3.51E+13	4229.454	31302.46	48749.79
4.65E+13	5839.054	6.59E+11	82.74335	2.28E+13	2858.682	3.35E+13	4200.638	37003.46	52279.49
4.71E+13	6273.675	4.82E+11	64.15988	2.43E+13	3229.437	3.08E+13	4100.994	43418.78	52559.99
4.56E+13	6558.366	3.48E+11	49.98455	2.54E+13	3652.131	2.78E+13	3997.614	50603.03	50344.04
1.49E+13	2275.245	3.68E+12	563.5787	2.51E+13	3840.317	2.88E+13	4410.545	5287.719	18163.79
1.76E+13	2542.709	4.08E+12	589.978	2.48E+13	3587.43	3.38E+13	4884.974	5842.846	21268.47
2.28E+13	3006.366	3.73E+12	492.6238	2.84E+13	3753.5	3.72E+13	4916.569	8017.064	26803.27
2.83E+13	3513.729	3.08E+12	382.0438	2.94E+13	3649.56	3.9E+13	4841.423	11685.99	33175.08
3.33E+13	3970.169	2.46E+12	293.6918	3.11E+13	3704.128	4.06E+13	4838.689	16318.04	38627.53
3.8E+13	4454.383	2.02E+12	236.4341	3.13E+13	3667.806	4.07E+13	4766.407	21221.87	43758.2
4.36E+13	5133.779	1.53E+12	180.1213	3.15E+13	3711.144	4.09E+13	4813.555	26007.33	49763.93
4.74E+13	5713.22	1.11E+12	134.031	3.1E+13	3730.89	3.86E+13	4650.405	31302.46	53398.96
4.95E+13	6211.946	7.88E+11	98.95449	3.04E+13	3821.031	3.53E+13	4435.432	37003.46	55745.88
4.96E+13	6610.199	5.74E+11	76.36979	3.09E+13	4114.239	3.17E+13	4224.393	43418.78	55362.63
5.33E+13	7664.569	4.19E+11	60.2261	3.07E+13	4408.924	2.91E+13	4183.053	50603.03	59249.07
1.49E+13	2275.245	3.68E+12	563.5787	2.51E+13	3840.317	2.88E+13	4410.545	5287.719	18163.79
1.76E+13	2542.709	4.08E+12	589.978	2.48E+13	3587.43	3.38E+13	4884.974	5842.846	21268.47
2.34E+13	3085.661	3.84E+12	506.9195	2.91E+13	3839.769	3.84E+13	5071.446	8017.064	27498.44
3.07E+13	3805.188	3.37E+12	418.4016	3.13E+13	3885.631	4.26E+13	5286.227	11685.99	35879.45
3.8E+13	4526.237	2.94E+12	350.1923	3.46E+13	4126.009	4.6E+13	5477.693	16318.04	43927.7
4.43E+13	5197.254	2.49E+12	292.4293	3.65E+13	4273.542	4.74E+13	5560.356	21221.87	51041.9
5.01E+13	5903.089	1.89E+12	222.1517	3.73E+13	4390.643	4.75E+13	5596.898	26007.33	57393.1
5.35E+13	6444.505	1.33E+12	160.0521	3.61E+13	4355.551	4.46E+13	5379.443	31302.46	60872.83
5.46E+13	6852.674	9.04E+11	113.5021	3.35E+13	4206.603	3.94E+13	4940.917	37003.46	61989.02
5.4E+13	7186.385	6.22E+11	82.80283	3.23E+13	4302.458	3.45E+13	4594.699	43418.78	60777.88
5.46E+13	7840.882	4.51E+11	64.78418	3.24E+13	4656.534	3.08E+13	4430.798	50603.03	60738.94
1.49E+13	2275.245	3.68E+12	563.5787	2.51E+13	3840.317	2.88E+13	4410.545	5287.719	18163.79
1.76E+13	2542.709	4.08E+12	589.978	2.48E+13	3587.43	3.38E+13	4884.974	5842.846	21268.47
2.34E+13	3089.787	3.84E+12	506.9613	2.91E+13	3841.265	3.84E+13	5072.315	8017.064	27538.55
3.11E+13	3860.165	3.42E+12	424.6863	3.17E+13	3932.749	4.32E+13	5357.077	11685.99	36398.78

3.98E+13	4741.397	3.1E+12	368.9959	3.59E+13	4283.081	4.81E+13	5731.822	16318.04	46033.26
4.76E+13	5581.516	2.69E+12	315.8886	3.86E+13	4529.668	5.13E+13	6015.547	21221.87	54940.16
5.46E+13	6431.782	2.06E+12	242.0003	4E+13	4705.862	5.14E+13	6051.66	26007.33	62495.74
5.92E+13	7129.271	1.48E+12	178.533	3.94E+13	4752.144	4.88E+13	5879.507	31302.46	67610.61
6.17E+13	7744.982	1.04E+12	130.4139	3.7E+13	4646.648	4.44E+13	5571.749	37003.46	70082.42
6.22E+13	8277.609	7.06E+11	93.9594	3.41E+13	4538.777	3.94E+13	5242.564	43418.78	70040.47
6.18E+13	8881.84	4.72E+11	67.87052	3.23E+13	4646.094	3.47E+13	4985.389	50603.03	69104.53
1.49E+13	2275.245	3.68E+12	563.5787	2.51E+13	3840.317	2.88E+13	4410.545	5287.719	18163.79
1.76E+13	2542.709	4.08E+12	589.978	2.48E+13	3587.43	3.38E+13	4884.974	5842.846	21268.47
2.34E+13	3091.159	3.84E+12	507.0614	2.91E+13	3843.439	3.84E+13	5073.877	8017.064	27549.72
3.12E+13	3869.093	3.44E+12	426.11	3.18E+13	3940.25	4.36E+13	5402.124	11685.99	36481.47
4.03E+13	4800.374	3.14E+12	374.6927	3.63E+13	4327.29	4.89E+13	5824.675	16318.04	46618.4
4.83E+13	5659.618	2.73E+12	320.547	3.91E+13	4580.144	5.15E+13	6032.597	21221.87	55696.18
5.61E+13	6610.731	2.11E+12	248.8045	4.09E+13	4814.413	5.28E+13	6211.896	26007.33	64131.75
6.25E+13	7534.523	1.57E+12	188.7637	4.13E+13	4971.172	5.17E+13	6224.025	31302.46	71430.45
6.74E+13	8456.205	1.13E+12	141.6117	3.97E+13	4980.976	4.85E+13	6091.048	37003.46	76512.61
6.96E+13	9268.71	7.87E+11	104.7328	3.75E+13	4990.918	4.42E+13	5879.032	43418.78	78414.84
6.94E+13	9974.781	5.27E+11	75.69043	3.56E+13	5117.543	3.9E+13	5602.098	50603.03	77598.23
1.51E+13	2314.913	3.04E+12	468.0656	2.41E+13	3700.999	3.25E+13	4992.728	4499.383	18078.07
1.77E+13	2578.007	3.21E+12	466.901	2.65E+13	3863.674	3.75E+13	5461.08	5239.969	20961.41
2.28E+13	2990.459	3.72E+12	488.8601	3.35E+13	4403.682	4.6E+13	6045.624	6732.211	26345.85
2.71E+13	3283.043	5.95E+12	719.7962	3.32E+13	4016.657	4.3E+13	5199.148	10016.56	31634.19
3.7E+13	4205.875	7.11E+12	809.4556	3.14E+13	3569.779	4.27E+13	4855.912	13034.33	44601.15
4.92E+13	5369.512	6.93E+12	755.5871	3.1E+13	3381.435	4.53E+13	4939.021	16318.79	62440.33
5.95E+13	6342.539	5.71E+12	608.4672	3.45E+13	3677.738	4.77E+13	5080.732	20259.99	83013.12
6.89E+13	7288.762	5.38E+12	568.4578	3.73E+13	3943.781	4.91E+13	5192.608	25365.17	101214.2
7.75E+13	8241.514	5.94E+12	631.0734	3.97E+13	4219.469	5.09E+13	5408.475	31574.82	114130.1
8.58E+13	9267.942	6.58E+12	710.8682	4.17E+13	4511.561	5.23E+13	5650.114	39556.37	125335.4
9.49E+13	10509.71	7.14E+12	790.6095	4.45E+13	4925.44	5.4E+13	5980.96	47741.57	138391.5
1.51E+13	2314.913	3.04E+12	468.0656	2.41E+13	3700.999	3.25E+13	4990.977	4499.383	18078.35
1.77E+13	2578.007	3.21E+12	466.901	2.65E+13	3863.674	3.75E+13	5462.01	5237.582	20965.29
2.28E+13	2997.575	3.93E+12	515.8304	3.34E+13	4389.412	4.61E+13	6059.347	6717.19	26410.3
2.82E+13	3416.855	5.75E+12	695.6226	3.76E+13	4546.326	4.88E+13	5911.918	10011.87	32428.64
3.48E+13	3957.848	6.85E+12	779.0765	3.94E+13	4481.373	5.2E+13	5919.717	13161.32	40040.59
4.45E+13	4852.953	8.2E+12	894.5199	3.79E+13	4137.082	5.57E+13	6076.022	16615.48	51553.1
5.57E+13	5939.075	9.4E+12	1001.927	4.06E+13	4331.107	5.8E+13	6181.254	20675.73	64916.16
6.83E+13	7226.138	8.69E+12	919.1434	4.47E+13	4729.012	5.92E+13	6259.352	25870.86	80639.79
7.95E+13	8450.484	8.9E+12	946.492	4.87E+13	5174.613	6.15E+13	6537.716	32203.8	96587.3
9.06E+13	9785.499	8.45E+12	912.644	5.23E+13	5653.896	6.27E+13	6780.323	40374.09	117412.6
1.03E+14	11363.55	8.64E+12	956.6781	5.67E+13	6272.503	6.42E+13	7106.29	49038.66	140093.2
1.51E+13	2314.913	3.04E+12	468.0656	2.41E+13	3700.999	3.25E+13	4990.977	4499.383	18078.35
1.77E+13	2578.007	3.21E+12	466.901	2.65E+13	3863.674	3.75E+13	5462.01	5236.345	20965.29
2.28E+13	2992.028	3.81E+12	500.5752	3.35E+13	4400.544	4.61E+13	6050.989	6715.635	26360.58
2.81E+13	3402.869	5.19E+12	627.775	4.02E+13	4865.828	5.13E+13	6204.052	10017.88	32166.97
3.41E+13	3876.289	5.78E+12	658.0344	4.52E+13	5146.963	5.59E+13	6366.963	13194.91	38730.86
4.19E+13	4567.453	6.04E+12	659.2491	4.68E+13	5101.22	6.08E+13	6625.997	16696.74	47542.26
5.24E+13	5579.002	6.44E+12	686.7271	4.43E+13	4716.28	6.5E+13	6925.551	20791.65	59637.27

6.14E+13	6487.874	8.38E+12	886.1868	4.8E+13	5077.612	6.75E+13	7139.84	26058.75	70466.45
7.28E+13	7740.836	1.14E+13	1215.374	5.29E+13	5624.266	6.84E+13	7275.002	32473.36	84391.46
8.69E+13	9386.36	1.22E+13	1321.599	5.77E+13	6233.709	6.92E+13	7473.421	40706.42	102350.1
1.01E+14	11159.75	1.23E+13	1359.118	6.32E+13	6993.671	7.15E+13	7915.352	49573.88	120892.9
1.51E+13	2314.913	3.04E+12	468.0656	2.41E+13	3700.999	3.25E+13	4990.977	4499.383	18078.35
1.77E+13	2578.007	3.21E+12	466.901	2.65E+13	3863.674	3.75E+13	5462.01	5235.96	20965.57
2.27E+13	2986.846	3.74E+12	490.9768	3.35E+13	4403.719	4.61E+13	6061.318	6715.307	26315.3
2.82E+13	3418.435	5.08E+12	614.3938	4.08E+13	4943.493	5.28E+13	6385.002	10016.52	32292.8
3.4E+13	3872.97	4.9E+12	557.0974	4.72E+13	5373.399	5.87E+13	6674.579	13204.24	38661.42
4.16E+13	4541.036	4.88E+12	532.404	5.06E+13	5523.805	6.4E+13	6979.267	16722.38	46994.76
5.18E+13	5522.587	5.58E+12	594.6445	4.91E+13	5236.66	6.92E+13	7368.944	20846.24	58641.16
6.14E+13	6493.396	7.41E+12	784.0271	4.98E+13	5264.954	7.36E+13	7778.353	26145.28	69847.83
6.97E+13	7404.246	9.26E+12	984.3174	5.51E+13	5856.947	7.57E+13	8050.467	32605.02	80204.79
7.94E+13	8582.348	1.13E+13	1216.749	6.05E+13	6534.902	7.72E+13	8344.491	40889.07	92983.13
9.27E+13	10267.01	1.35E+13	1489.112	6.66E+13	7375.229	7.84E+13	8680.036	49832.77	109399.8
1.51E+13	2314.913	3.04E+12	468.0656	2.41E+13	3700.999	3.25E+13	4990.977	4499.383	18078.35
1.77E+13	2578.007	3.21E+12	466.901	2.65E+13	3863.674	3.75E+13	5462.01	5235.758	20965.29
2.27E+13	2986.846	3.7E+12	485.8309	3.35E+13	4403.719	4.62E+13	6066.646	6714.818	26315.3
2.84E+13	3443.113	4.49E+12	543.4867	4.12E+13	4986.192	5.39E+13	6521.067	10012.49	32525.3
3.44E+13	3910.62	3.95E+12	449.269	4.81E+13	5469.816	6.03E+13	6860.647	13205.54	38996.42
4.18E+13	4559.334	3.59E+12	391.9262	5.24E+13	5716.451	6.62E+13	7217.385	16732.53	47239.2
5.23E+13	5576.812	3.75E+12	399.2317	5.2E+13	5545.171	7.27E+13	7750.18	20864.82	58873.94
6.34E+13	6701.094	5.42E+12	572.6582	5.21E+13	5511.63	7.79E+13	8233.783	26178.99	71102.83
7.19E+13	7645.136	7.64E+12	812.4937	5.76E+13	6119.363	8.28E+13	8806.858	32680.97	81494.51
7.99E+13	8633.227	1.09E+13	1175.025	6.39E+13	6903.484	8.8E+13	9504.988	41039.12	92134.52
8.91E+13	9868.995	1.21E+13	1337.221	7.08E+13	7835.854	9.25E+13	10241.27	50056.19	103911.2
1.51E+13	2314.913	3.04E+12	468.0656	2.41E+13	3700.999	3.25E+13	4990.806	4499.383	18077.79
1.77E+13	2578.007	3.21E+12	466.901	2.65E+13	3863.674	3.75E+13	5462.01	5234.862	20965.29
2.27E+13	2988.306	3.48E+12	457.6562	3.35E+13	4403.865	4.63E+13	6083.762	6713.662	26327.8
2.86E+13	3464.362	3.95E+12	477.6564	4.14E+13	5008.415	5.45E+13	6602.329	10011.61	32725.03
3.44E+13	3912.927	3.41E+12	388.2264	4.85E+13	5516.475	6.11E+13	6952.985	13207.64	39025.31
4.18E+13	4563.515	3.18E+12	346.5746	5.31E+13	5792.37	6.74E+13	7348.926	16733.81	47290.87
5.24E+13	5580.246	3.26E+12	347.1374	5.32E+13	5672.891	7.44E+13	7922.772	20868.41	58898.94
6.41E+13	6779.696	3.84E+12	405.8777	5.3E+13	5601.511	8.07E+13	8537.824	26179.49	71849.22
7.29E+13	7748.513	5.38E+12	571.9582	5.87E+13	6235.88	8.67E+13	9214.197	32691.37	82394.79
8.11E+13	8762.902	8.68E+12	937.8885	6.58E+13	7105.38	9.24E+13	9980.011	41056.78	93178.69
9.13E+13	10104.07	1.03E+13	1136.678	7.3E+13	8078.652	9.77E+13	10820.44	50104.49	105397.6
1.52E+13	2338.436	3.07E+12	473.2591	2.31E+13	3554.893	3.53E+13	5435.19	5208.629	18070.43
1.71E+13	2481.029	3.5E+12	509.0505	2.55E+13	3699.594	3.73E+13	5416.631	5468.496	20272.07
2.12E+13	2749.881	4.38E+12	568.5572	3.21E+13	4171.628	4.48E+13	5822.349	6641.204	25103.02
2.5E+13	2939.688	5.29E+12	621.5556	3.62E+13	4249.72	5.2E+13	6110.651	7462.289	29705
2.72E+13	2940.626	5.79E+12	625.1852	3.08E+13	3332.432	4.77E+13	5150.239	7663.83	33032.28
3.2E+13	3214.756	6.52E+12	654.8523	3.16E+13	3176.86	5.01E+13	5031.925	7680.927	39278.95
3.76E+13	3556.682	7.08E+12	669.4499	3.19E+13	3016.93	5.28E+13	4988.734	7654.867	45866.73
4.49E+13	4040.69	7.74E+12	696.3479	3.09E+13	2782.058	5.43E+13	4884.222	7657.209	54747.6
5.24E+13	4502.861	8.33E+12	715.7954	3.06E+13	2629.387	5.64E+13	4845.512	7632.232	63517.3
6.05E+13	4985.775	8.86E+12	730.2682	3.11E+13	2566.328	5.92E+13	4882.278	7607.777	72840.42

6.89E+13	5457.062	9.4E+12	745.17	3.26E+13	2583.649	6.32E+13	5011.13	7654.994	82404.57
1.52E+13	2338.436	3.07E+12	473.2591	2.31E+13	3554.893	3.53E+13	5435.19	5208.629	18070.43
1.71E+13	2481.029	3.5E+12	509.0505	2.55E+13	3699.594	3.73E+13	5416.631	5468.496	20272.07
2.12E+13	2749.881	4.38E+12	568.5572	3.21E+13	4171.628	4.48E+13	5822.349	6641.204	25103.02
2.56E+13	3006.928	5.29E+12	621.7742	3.8E+13	4461.771	5.27E+13	6185.965	7481.556	30377.94
2.73E+13	2952.254	5.71E+12	616.2912	3.65E+13	3941.563	5.29E+13	5711.447	7790.58	32693.72
2.98E+13	2988.927	5.87E+12	590.002	3.7E+13	3715.012	5.52E+13	5541.014	7844.66	36056.58
3.5E+13	3307.82	6.52E+12	616.179	3.57E+13	3375.623	5.63E+13	5320.966	7784.985	42708.34
3.86E+13	3471.665	6.79E+12	610.6761	3.64E+13	3275.738	5.93E+13	5335.493	7839.911	46839.82
4.35E+13	3741.987	7.25E+12	623.2602	3.67E+13	3156.002	6.23E+13	5357.201	7888.352	52594.46
4.97E+13	4096.55	7.8E+12	643.2102	3.7E+13	3046.912	6.53E+13	5379.852	7918.375	59785.1
5.75E+13	4552.695	8.47E+12	671.1876	3.72E+13	2948.998	6.82E+13	5402.594	7962.038	68790.86
1.52E+13	2338.436	3.07E+12	473.2591	2.31E+13	3554.893	3.53E+13	5435.19	5208.629	18070.43
1.71E+13	2481.029	3.5E+12	509.0505	2.55E+13	3699.594	3.73E+13	5416.631	5468.496	20272.07
2.12E+13	2749.881	4.38E+12	568.5572	3.21E+13	4171.628	4.48E+13	5822.349	6641.204	25103.02
2.57E+13	3016.52	5.3E+12	621.9699	3.81E+13	4478.736	5.27E+13	6192.151	7482.668	30472.08
2.83E+13	3054.405	5.78E+12	624.8581	3.88E+13	4186.93	5.54E+13	5988.598	7831.169	33600.19
3.09E+13	3107.435	5.91E+12	594.0359	4.01E+13	4025.067	5.88E+13	5908.542	7932.493	36842.2
3.36E+13	3182.02	5.89E+12	556.9503	4.16E+13	3931.809	6.32E+13	5980.584	7981.957	40068.81
3.59E+13	3226.905	5.93E+12	533.2447	4.22E+13	3795.748	6.64E+13	5972.142	8066.167	42958.65
3.9E+13	3349.306	6.12E+12	526.4127	4.26E+13	3665.096	6.97E+13	5991.725	8125.556	46725.73
4.33E+13	3566.581	6.37E+12	525.358	4.41E+13	3632.688	7.43E+13	6127.184	8211.324	51708.07
4.87E+13	3860.15	6.84E+12	541.7889	4.59E+13	3639.689	7.94E+13	6287.893	8359.974	58057.85
1.52E+13	2338.436	3.07E+12	473.2591	2.31E+13	3554.893	3.53E+13	5435.19	5208.629	18070.43
1.71E+13	2480.467	3.5E+12	508.9293	2.56E+13	3723.093	3.73E+13	5418.072	5468.341	20257.79
2.16E+13	2805.124	4.39E+12	570.2784	3.34E+13	4336.779	4.5E+13	5847.663	6643.545	25499.49
2.68E+13	3146.008	5.36E+12	629.4932	3.97E+13	4659.396	5.3E+13	6225.712	7495.633	31454.36
3.17E+13	3424.507	6.09E+12	657.3523	4.38E+13	4735.041	5.92E+13	6397.873	7888.323	36993.81
3.72E+13	3733.843	6.5E+12	652.6456	4.61E+13	4631.896	6.46E+13	6490.225	8030.021	43145.95
4.14E+13	3918.472	6.52E+12	616.3235	4.76E+13	4502.371	6.93E+13	6551.393	8095.101	47918.26
4.57E+13	4107.857	6.52E+12	586.4698	4.94E+13	4441.292	7.4E+13	6658.851	8221.48	52618.68
5.01E+13	4306.181	6.51E+12	559.5572	5.11E+13	4394.278	7.9E+13	6793.3	8337.471	57502.46
5.47E+13	4505.269	6.5E+12	535.3984	5.35E+13	4405.529	8.47E+13	6979.207	8473.564	62617.91
5.96E+13	4724.22	6.58E+12	521.4004	5.59E+13	4430.069	9.05E+13	7174.015	8670.668	68261.69

1.83E+13	2647.124	2.7E+12	391.8242	2.73E+13	3965.655	4.85E+13	7034.356		21774.74
2.58E+13	3382.464	2.77E+12	362.8974	3.26E+13	4280.812	5.85E+13	7668.824		30534.68
3.66E+13	4434.248	1.74E+12	210.5956	3.71E+13	4487.786	5.78E+13	6997.391		42948.64
4.73E+13	5396.02	1.22E+12	139.3984	4.13E+13	4707.281	6.04E+13	6893.179		55182.51
5.79E+13	6328.636	7.35E+11	80.39993	4.33E+13	4738.714	6.18E+13	6761.814		67236.75
6.72E+13	7164.145	3.76E+11	40.11658	4.39E+13	4682.628	6.29E+13	6702.482		77644.76
7.5E+13	7918.415	1.55E+11	16.37624	4.27E+13	4504.116	6.48E+13	6838.367		86294.33
8.11E+13	8561.544	4.9E+10	5.173239	3.94E+13	4158.413	6.8E+13	7183.837		93087.02
8.63E+13	9178.985	1.2E+10	1.275241	3.48E+13	3704.193	7.33E+13	7799.43		99015.45
9.27E+13	9981.105	2.16E+09	0.232104	2.99E+13	3217.881	8.25E+13	8877.379		106456.6

1.83E+13	2647.124	2.7E+12	391.8242	2.73E+13	3965.655	4.85E+13	7034.356		21774.74
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2.58E+13	3382.464	2.77E+12	362.8974	3.26E+13	4280.812	5.85E+13	7668.824	30534.68
3.39E+13	4100.862	2.2E+12	266.1965	3.81E+13	4611.96	6.21E+13	7524.759	39787.96
4.27E+13	4866.564	1.74E+12	198.5713	4.29E+13	4895.518	6.55E+13	7466.871	49818.88
5.16E+13	5640.572	1.22E+12	133.4531	4.58E+13	5010.112	6.66E+13	7282.795	59913.77
5.99E+13	6392.78	7.58E+11	80.81172	4.77E+13	5089.866	6.65E+13	7088.408	69248.21
6.83E+13	7213.235	3.96E+11	41.78878	4.81E+13	5082.47	6.67E+13	7037.082	78583.35
7.53E+13	7948.865	1.69E+11	17.87757	4.65E+13	4907.886	6.76E+13	7140.04	86317.8
8.07E+13	8582.725	5.77E+10	6.142164	4.31E+13	4582.122	7.02E+13	7466.6	92352.72
8.55E+13	9204.465	1.49E+10	1.608468	3.84E+13	4128.692	7.51E+13	8078.998	97890.16
1.83E+13	2647.124	2.7E+12	391.8242	2.73E+13	3965.655	4.85E+13	7034.356	21774.74
2.58E+13	3382.464	2.77E+12	362.8974	3.26E+13	4280.812	5.85E+13	7668.824	30534.68
3.31E+13	4005.04	2.44E+12	295.1156	3.85E+13	4667.72	6.45E+13	7809.819	38892.66
4.08E+13	4651.228	2.06E+12	234.7818	4.37E+13	4982.197	6.86E+13	7830.088	47641.58
4.83E+13	5277.179	1.57E+12	171.5093	4.7E+13	5142.154	7.02E+13	7677.387	56050.92
5.53E+13	5902.291	1.09E+12	115.7439	4.96E+13	5290.663	7E+13	7468.61	63897.08
6.3E+13	6646.449	6.54E+11	69.01885	5.09E+13	5376.282	6.94E+13	7327.44	72360.04
6.57E+13	6934.81	5.21E+11	54.99807	5.29E+13	5586.718	7.11E+13	7508.503	75231.06
6.82E+13	7250.226	3.93E+11	41.77911	5.43E+13	5770.549	7.26E+13	7719.117	77866.11
7.16E+13	7702.751	2.49E+11	26.80119	5.43E+13	5842.292	7.34E+13	7899.484	81602.56
1.83E+13	2647.124	2.7E+12	391.8242	2.73E+13	3965.655	4.85E+13	7034.356	21774.74
2.58E+13	3382.464	2.77E+12	362.8974	3.26E+13	4280.812	5.85E+13	7668.824	30534.68
3.29E+13	3982.036	2.78E+12	337.0662	3.92E+13	4748.09	6.83E+13	8274.381	38727.64
3.93E+13	4485.008	2.61E+12	297.2324	4.48E+13	5108.76	7.44E+13	8492.614	46002.39
4.46E+13	4877.283	2.32E+12	253.2199	4.88E+13	5337.859	7.83E+13	8555.195	51838.17
4.87E+13	5188.893	1.98E+12	211.1889	5.26E+13	5605.158	8.02E+13	8555.108	56142.77
5.24E+13	5532.001	1.6E+12	169.1156	5.56E+13	5869.716	8.09E+13	8541.819	60098.59
5.57E+13	5875.698	1.23E+12	129.7738	5.76E+13	6080.94	8.05E+13	8499.517	63608.32
5.91E+13	6287.477	8.81E+11	93.67213	5.88E+13	6249.352	7.97E+13	8472.635	67401.37
6.29E+13	6773.608	5.87E+11	63.18185	5.92E+13	6371.888	7.88E+13	8483.114	71639.8
1.54E+13	2374.244	2.65E+12	407.3741	2.5E+13	3840.005	4.37E+13	6720.458	18628.99
1.83E+13	2647.124	2.7E+12	391.8242	2.73E+13	3965.655	4.85E+13	7034.356	21774.74
2.6E+13	3410.667	2.8E+12	366.7636	3.3E+13	4324.716	5.97E+13	7831.7	30802.54
3.32E+13	4015.954	2.81E+12	340.0462	3.94E+13	4765.787	6.89E+13	8338.779	39065.4
3.96E+13	4511.972	2.66E+12	303.0147	4.5E+13	5135.107	7.53E+13	8591.109	46290.52
4.48E+13	4893.816	2.41E+12	263.0228	4.92E+13	5374.452	7.96E+13	8702.584	52032.75
4.85E+13	5167.334	2.13E+12	227.0569	5.31E+13	5659.404	8.23E+13	8774.143	55926.61
5.16E+13	5451.945	1.82E+12	192.5134	5.64E+13	5952.551	8.39E+13	8861.413	59238.27
5.39E+13	5687.937	1.55E+12	163.1917	5.88E+13	6211.795	8.48E+13	8958.1	61561.9
5.57E+13	5920.627	1.29E+12	136.9573	6.07E+13	6458.606	8.55E+13	9094.316	63411.36
5.71E+13	6146.81	1.06E+12	114.1922	6.23E+13	6709.111	8.64E+13	9294.655	64900.67
1.49E+13	2284.569	3.06E+12	470.5786	2.41E+13	3711.251		4562.644	18397.24
1.75E+13	2537.232	2.93E+12	424.2823	2.6E+13	3770.19		4779.518	21525.02
2.44E+13	3226.889	2.97E+12	392.8322	3.79E+13	5017.071		6238.012	29194.47
2.89E+13	3593.8	2.22E+12	275.0188	4.95E+13	6149.468		8602.663	33250.03
4.01E+13	4776.737	2.05E+12	244.4565	4.74E+13	5636.219		11989.97	44555.59

6.46E+13	7534.554	4.14E+12	482.1208	4.26E+13	4963.675	16183.32	69861.17
8.94E+13	10407.38	7.19E+12	837.6354	3.83E+13	4456.608	21530.24	97000.08
1.1E+14	12961	9.92E+12	1173.256	4.07E+13	4815.213	26477.19	120805.7
1.26E+14	15403.13	1.13E+13	1377.372	4.6E+13	5613.148	34770.27	141833.4
1.44E+14	18324.62	1.16E+13	1480.939	4.94E+13	6310.395	43764.09	161861.2
1.57E+14	21258.02	1.19E+13	1607.158	5.43E+13	7359.705	54632.8	177583.5
1.49E+13	2284.569	3.06E+12	470.5786	2.41E+13	3711.251	4562.644	18397.24
1.75E+13	2537.232	2.93E+12	424.2823	2.6E+13	3770.19	4779.518	21525.02
2.44E+13	3226.889	2.97E+12	392.8322	3.79E+13	5017.071	6238.012	29194.47
3.26E+13	4045.612	2.91E+12	361.1045	5.24E+13	6508.159	8741.062	37527.81
4.28E+13	5087.473	2.96E+12	352.0571	5.73E+13	6819.66	12574.02	47472.26
5.93E+13	6909.643	2.89E+12	336.4161	6.06E+13	7058.585	17174.51	63750.05
7.9E+13	9194.584	4.42E+12	514.5474	5.71E+13	6642.869	22601.73	85194.51
1.01E+14	11890.23	7.48E+12	883.8839	5.22E+13	6171.75	27671.52	109389
1.19E+14	14454.62	1.04E+13	1270.326	5.34E+13	6510.845	36136.41	132139
1.37E+14	17526.51	1.29E+13	1651.912	5.41E+13	6906.318	45118.25	155472.3
1.51E+14	20500.96	1.42E+13	1928.815	5.86E+13	7939.743	56029.77	172583.5
1.49E+13	2284.569	3.06E+12	470.5786	2.41E+13	3711.251	4562.644	18397.24
1.75E+13	2537.232	2.93E+12	424.2823	2.6E+13	3770.19	4779.518	21525.02
2.44E+13	3226.889	2.97E+12	392.8322	3.79E+13	5017.071	6238.012	29194.47
3.41E+13	4231.855	3.37E+12	418.357	5.24E+13	6504.71	8755.365	39305.59
4.48E+13	5325.483	3.48E+12	414.5348	5.88E+13	6994.862	12683.09	49861.15
5.99E+13	6984.114	3.4E+12	396.3169	6.56E+13	7644.642	17478.64	64555.61
7.57E+13	8812.959	3.39E+12	394.2384	6.7E+13	7797.447	23078.95	81694.51
9.23E+13	10914.7	5.11E+12	603.7081	6.18E+13	7308.219	28227.32	100139
1.13E+14	13743.24	7.87E+12	959.3504	6.09E+13	7422.093	36794.54	122777.9
1.31E+14	16707.12	1.14E+13	1450.788	6.08E+13	7768.278	45999.27	144944.6
1.45E+14	19615.83	1.44E+13	1945.764	6.31E+13	8553.679	57033.44	163194.6
1.49E+13	2284.569	3.06E+12	470.5786	2.41E+13	3711.251	4562.644	18397.24
1.75E+13	2537.232	2.93E+12	424.2823	2.6E+13	3770.19	4779.518	21525.02
2.44E+13	3226.889	2.97E+12	392.8322	3.79E+13	5017.071	6238.012	29194.47
3.43E+13	4259.447	3.4E+12	422.4957	5.25E+13	6521.954	8761.629	39555.59
4.51E+13	5361.846	3.95E+12	470.4012	5.96E+13	7094.033	12719.24	50250.04
5.94E+13	6922.594	4.39E+12	512.2331	6.86E+13	8000.809	17596.93	64055.61
7.31E+13	8505.718	4.14E+12	482.2063	7.45E+13	8670.658	23348.07	78833.4
8.7E+13	10290.63	4.23E+12	499.5865	7.3E+13	8631.909	28665.14	94277.85
1.03E+14	12598.25	5.09E+12	620.2579	7.54E+13	9190.387	37538.67	112139
1.18E+14	15110.9	6.68E+12	853.0917	7.63E+13	9744.045	47148.37	128611.2
1.28E+14	17318.28	7.91E+12	1072.317	8.18E+13	11088.52	58687.56	139250.1
1.49E+13	2284.569	3.06E+12	470.5786	2.41E+13	3711.251	4562.644	18397.24
1.75E+13	2537.232	2.93E+12	424.2823	2.6E+13	3770.19	4779.518	21525.02
2.44E+13	3226.889	2.97E+12	392.8322	3.79E+13	5017.071	6238.012	29194.47
3.54E+13	4390.507	3.48E+12	431.463	5.33E+13	6615.076	8770.579	40833.37
4.76E+13	5659.359	4.28E+12	509.4084	6.19E+13	7371.712	12792.26	53111.15
6.09E+13	7103.916	5.24E+12	610.6648	7.31E+13	8518.871	17774.08	65888.94
7.05E+13	8211.414	5.86E+12	682.3979	8.29E+13	9647.36	23643.05	76416.73
8.01E+13	9469.481	5.94E+12	702.5744	8.57E+13	10136.25	29048.21	87111.18

9.3E+13	11338.08	5.6E+12	683.2661	9.01E+13	10992.56	37993.96	101027.9
1.08E+14	13805.54	5.41E+12	690.9865	8.92E+13	11389.93	47585.07	117194.5
1.18E+14	15969.88	5.66E+12	767.6089	9.31E+13	12617.71	59163.59	128000.1
1.49E+13	2284.569	3.06E+12	470.5786	2.41E+13	3711.251	4562.644	18397.24
1.75E+13	2537.232	2.93E+12	424.2823	2.6E+13	3770.19	4779.518	21525.02
2.49E+13	3298.246	2.93E+12	388.0506	3.8E+13	5035.462	6236.758	29750.02
3.56E+13	4424.996	3.48E+12	432.4977	5.4E+13	6704.748	8765.831	41194.48
4.96E+13	5900.675	4.49E+12	534.5317	6.41E+13	7632.862	12816.85	55666.71
6.49E+13	7560.457	5.54E+12	645.9577	7.69E+13	8965.699	17869.22	70416.72
7.61E+13	8864.705	5.95E+12	692.7471	9.04E+13	10527.04	23856.1	82694.51
8.58E+13	10139.54	5.89E+12	696.6621	9.91E+13	11716.14	29372.12	93333.41
9.57E+13	11670.06	5.68E+12	692.0737	1.12E+14	13614.51	38463.41	104139
1.06E+14	13532.41	5.73E+12	731.0694	1.15E+14	14642.67	48129.23	115194.5
1.14E+14	15514.14	6.08E+12	823.7295	1.17E+14	15864.42	59647.46	124666.8

Secondary electricity, kWh	Secondary electricity (biomass)	Secondary electricity (biomass CCS)	Secondary electricity (coal)	Secondary electricity (coal CCS)	Secondary electricity (gas)	Secondary electricity (gas CCS)	Secondary electricity (geothermal)	Secondary electricity (hydro)	Secondary electricity (renewables excl. bio)
1.82E+13	220.7747	0	7248.086	0	3659.013	0		2931.677	3098.927
2.13E+13	337.5229	0	8598.18	0	4721.203	0		3440.925	3884.651
2.41E+13	590.5518	1.691102	7659.459	2.005331	6051.049	64.02549		4400.892	6275.659
2.26E+13	1424.46	388.0921	2389.521	17.12421	6910.707	451.667		4935.918	7578.488
2.75E+13	1950.284	1850.351	701.0448	361.254	4179.544	2213.776		5947.516	18310.6
3.53E+13	2200.792	2152.8	843.6452	761.9188	3270.78	2982.81		5483.807	27915.25
4.25E+13	2972.93	2965.848	1217.286	1216.945	4258.255	4192.274		5231.179	33147.52
4.87E+13	3986.174	3986.167	1736.142	1736.142	6384.864	6204.566		5738.335	35662.13
5.23E+13	4444.47	4444.466	1634.224	1634.223	5725.751	5457.803		6130.361	39272.95
5.26E+13	4555.406	4554.318	1108.42	1108.419	3587.769	3386.83		6194.5	41828.41
5.03E+13	5066.722	5064.533	567.2509	567.2504	2824.377	2418.287		6056.463	40514.62
1.82E+13	220.7747	0	7248.086	0	3659.013	0		2931.677	3098.927
2.13E+13	337.5229	0	8598.181	0	4721.204	0		3440.925	3884.651
2.68E+13	282.6268	0	9797.712	0	6553.67	0		4556.901	6324.403
3.32E+13	349.9675	0.021438	8994.818	430.9574	10282.6	185.7103		5383.296	9816.821
3.86E+13	604.5869	376.4895	7189.742	1649.656	11276.27	959.682		5999.935	16883.14
4.38E+13	1306.503	1184.511	4788.247	2284.781	9709.737	1415.349		6230.208	26843.84
4.98E+13	2554.962	2473.795	3827.251	3479.283	7446.296	1735.045		6429.991	35140.68
5.34E+13	2977.639	2958.792	4153.845	4119.203	5243.627	2171.934		6325.502	40427.96
5.57E+13	3777.685	3776.385	3974.728	3968.477	4518.927	2732.195		6301.908	42897.89
5.54E+13	3801.057	3800.733	3799.897	3796.19	4701.23	3097.692		6765.514	42369.18
5.92E+13	2691.831	2691.18	2775.39	2773.03	5243.972	3143.19		6961.117	47834.12
1.82E+13	220.7747	0	7248.086	0	3659.013	0		2931.677	3098.927
2.13E+13	337.5229	0	8598.181	0	4721.204	0		3440.925	3884.651
2.75E+13	286.0853	0	10262.82	0	6681.725	0		4598.673	6361.318
3.59E+13	281.2452	0	11682.9	0	10974.07	0		5385.526	9245.662
4.39E+13	164.7051	0	12504.78	1.7188	13668.05	0		6049.594	15119.81
5.1E+13	111.0696	0.131225	10707.05	149.0949	14153.74	0		6255.683	25088.23
5.74E+13	87.56099	6.491105	8880.05	852.5055	13752.29	39.66548		6488.066	34040.48
6.09E+13	100.6978	48.09954	7707.262	2188.942	9928.461	294.3487		6624.78	42751.75
6.2E+13	678.0674	657.956	6429.283	3592.17	6986.804	629.9171		6678.28	47652.62
6.08E+13	2533.514	2520.881	5117.421	4086.57	5427.247	1269.352		6875.217	47418.25
6.07E+13	2410.112	2403.134	4560.338	3996.248	5554.299	1520.088		7019.072	47877.7
1.82E+13	220.7747	0	7248.086	0	3659.013	0		2931.677	3098.927
2.13E+13	337.5229	0	8598.181	0	4721.204	0		3440.925	3884.651
2.75E+13	290.4782	0	10285.93	0	6699.805	0		4598.912	6360.015
3.64E+13	204.9365	0	12344.12	0	11063.57	0		5386.782	9094.41

4.6E+13	106.9587	0	15204.43	0	14148.5	0	6051.113	14175.72
5.49E+13	64.02424	0	16041.59	0	15193.94	0	6272.705	22722.56
6.25E+13	28.94641	0	16040.14	0	15427.03	0	6497.588	30461.77
6.76E+13	31.6211	0	14056.36	10.86542	13285.91	0	6706.489	39963.88
7.01E+13	26.92196	0.243417	10975.93	332.1368	11073.58	1.499665	6833.006	47904.96
7E+13	26.06968	5.549256	8594.95	841.0416	9993.902	10.60778	6969.508	51298.89
6.91E+13	29.37204	15.5708	6532.683	1134.623	10450.65	12.32304	7163.386	51954.24
1.82E+13	220.7747	0	7248.086	0	3659.013	0	2931.677	3098.927
2.13E+13	337.5229	0	8598.181	0	4721.204	0	3440.925	3884.651
2.75E+13	295.4377	0	10294.84	0	6691.541	0	4599.779	6360.217
3.65E+13	269.1332	0	12499.31	0	10976.07	0	5386.874	9051.183
4.66E+13	116.3887	0	15936.49	0	14243.73	0	6051.11	13965.58
5.57E+13	64.24634	0	17402.8	0	15278.12	0	6276.297	22045.46
6.41E+13	34.38261	0	18746.66	0	15789.26	0	6496.944	29043.49
7.14E+13	20.46903	0	19601.2	0	14168.06	0	6720.491	37396.36
7.65E+13	6.87455	0	17875.14	0	12282.04	0	6871.064	46286.1
7.84E+13	4.675817	0	15984	0	12051.7	0	7030.225	50319.66
7.76E+13	3.402284	0	13909.07	0	13084.64	0	7301.445	50564.1
1.81E+13	125.8334	0	7312.506	0	3690.559	0	56.66671	2946.113
2.1E+13	212.5002	0	8618.34	0	4535.004	0	98.05563	3576.392
2.63E+13	461.1115	0	8568.34	0	6958.339	0	88.61118	4267.781
3.16E+13	230.0002	17.77779	1286.945	376.9447	9736.397	1383.89	211.9446	5970.005
4.46E+13	411.3892	229.4446	527.7782	526.1115	7903.062	5404.449	652.5005	7799.451
6.24E+13	1128.89	936.3896	278.0558	276.3891	6828.894	6031.671	992.5008	8609.729
8.3E+13	1645.835	1372.501	178.3335	178.3335	4916.671	4179.17	1317.779	9399.452
1.01E+14	1609.724	1441.39	86.11118	86.11118	2598.058	2208.335	1628.89	9977.508
1.14E+14	1716.946	1653.612	21.66668	21.66668	724.1672	615.556	1672.501	10242.79
1.25E+14	1364.168	1319.168	4.16667	4.16667	0.555556	0.555556	1718.89	10421.4
1.38E+14	1206.668	1170.556	0.277778	0.277778	0.277778	0.277778	1748.613	10539.18
1.81E+13	125.8334	0	7310.561	0	3693.059	0	56.66671	2945.558
2.1E+13	219.1668	0	8592.785	0	4557.781	0	98.05563	3575.558
2.64E+13	468.0559	0	8521.951	0.277778	7015.839	18.33335	88.61118	4267.226
3.24E+13	315.5558	9.72223	4150.003	129.1668	12089.18	1090.834	52.22226	5359.171
4E+13	83.61118	36.94447	1442.223	500.556	15755.01	4829.171	87.22229	6021.949
5.16E+13	174.7224	112.7779	1006.39	1005.834	16174.46	12335.84	151.6668	7393.061
6.49E+13	435.2781	381.3892	1110.279	1109.723	15115.57	13710.57	231.1113	8125.007
8.06E+13	1026.945	978.0563	1065.556	1065.556	11768.34	10226.67	409.4448	9145.285
9.66E+13	1298.89	1271.39	735.5561	735.5561	7223.895	6140.283	849.7229	9863.619
1.17E+14	1416.668	1375.557	620.8338	620.8338	4309.448	3663.058	1297.779	10396.4
1.4E+14	1309.168	1278.334	481.3893	481.3893	1391.946	1183.057	1686.946	10535.29
1.81E+13	125.8334	0	7310.561	0	3693.059	0	56.66671	2945.558
2.1E+13	219.1668	0	8592.785	0	4557.781	0	98.05563	3575.558
2.64E+13	463.6115	0	8617.785	0.277778	6905.839	9.72223	88.61118	4244.17
3.22E+13	359.7225	3.333336	7125.839	11.11112	11945.29	9.72223	52.50004	4766.115
3.87E+13	192.2224	17.77779	3360.003	114.4445	17317.79	316.9447	8.611118	5940.283
4.75E+13	255.8335	70.55561	897.2229	331.1114	21151.96	1448.89	58.0556	6376.672
5.96E+13	409.167	245.8335	880.834	759.7228	20596.13	5661.393	122.2223	7497.784

7.05E+13	631.6672	626.1116	916.6674	916.6674	15730.85	12483.62	199.4446	8322.784	32274.75
8.44E+13	947.7785	943.0563	1063.334	1063.334	14141.12	13326.12	345.0003	9012.785	40142.53
1.02E+14	1196.112	1181.945	967.5008	967.5008	11258.62	10202.79	609.4449	9917.508	56272.55
1.21E+14	1345.279	1323.89	1036.112	1036.112	6845.561	5818.616	1107.779	10352.51	75690.34
1.81E+13	125.8334	0	7310.561	0	3693.059	0	56.66671	2945.558	3113.891
2.1E+13	219.1668	0	8592.785	0	4557.781	0	98.05563	3575.558	4203.892
2.63E+13	463.0559	0	8638.062	0	7015.561	0	88.61118	4244.17	6438.338
3.23E+13	333.3336	1.111112	7480.562	4.16667	12156.12	0	50.27782	4696.393	8839.729
3.87E+13	131.6668	5.55556	4726.393	21.94446	18010.57	0	6.388894	5748.893	12464.73
4.7E+13	82.22229	23.33335	3206.947	68.33339	22761.41	0	6.388894	6057.227	16181.12
5.86E+13	134.1668	72.77784	2621.669	163.0557	25982.8	79.72229	3.888892	6434.45	21982.8
6.98E+13	227.778	195.0002	1531.112	314.1669	25139.74	629.1672	3.611114	7122.228	28325.3
8.02E+13	450.0004	448.3337	527.5004	527.5004	20442.79	3561.67	21.94446	8229.173	34250.58
9.3E+13	706.3895	705.2783	841.6673	841.6673	11993.62	8883.063	156.9446	9525.285	43017.53
1.09E+14	935.0007	933.8896	1278.612	1278.612	10248.34	9586.674	343.6114	9910.563	54616.15
1.81E+13	125.8334	0	7310.561	0	3693.059	0	56.66671	2945.558	3113.891
2.1E+13	219.1668	0	8592.785	0	4557.781	0	98.05563	3575.281	4203.614
2.63E+13	471.9448	0	8659.451	0	7096.395	0	88.88896	4180.837	6340.005
3.25E+13	332.2225	0	8245.284	0	12310.57	0	45.55559	4639.448	8383.896
3.9E+13	199.7224	0	7210.561	0	18007.79	0	3.333336	5650.838	11324.45
4.72E+13	376.667	0	7340.839	0	23130.02	0	3.333336	5863.06	14389.18
5.89E+13	410.0003	0	8593.618	5.277782	27489.74	0	1.944446	6127.505	19054.74
7.11E+13	478.6115	0	8911.396	33.88892	30860.86	0	1.111112	6480.839	24866.69
8.15E+13	900.5563	0.277778	6754.728	116.1112	31343.64	0	1.111112	6741.672	30905.58
9.21E+13	1162.779	3.888892	4409.448	298.3336	31432.25	0	1.111112	7040.561	36926.7
1.04E+14	1602.501	15.55557	1334.168	481.9448	29607.25	0	0.833334	9180.285	42821.98
1.81E+13	125.8334	0	7310.561	0	3692.781	0	56.66671	2945.28	3113.614
2.1E+13	219.1668	0	8593.062	0	4557.504	0	98.05563	3575.281	4203.614
2.63E+13	471.9448	0	8876.952	0	7099.172	0	88.88896	4243.892	6301.672
3.27E+13	338.0558	0	8971.674	0	12163.62	0	44.1667	4695.004	8036.395
3.9E+13	230.278	0	9048.618	0	17310.57	0	0	5274.171	10309.73
4.73E+13	450.0004	0	10288.06	0	22541.68	0	0	5425.56	12548.9
5.89E+13	432.5003	0	13201.68	0	27015.02	0	0	5646.949	16316.4
7.18E+13	510.8337	0	16091.68	0	30594.47	0	0	6151.394	21334.46
8.24E+13	908.0563	0	19194.74	0	31508.91	0	0	6599.728	24613.08
9.32E+13	1221.668	0	19606.13	0	31691.14	0	0	6855.005	29538.36
1.05E+14	1596.112	0	17395.01	0	34126.42	0	0	6925.283	36363.92
1.81E+13	377.1947	0	7025.922	0	3706.531	0	53.94449	2895.725	3064.308
2.03E+13	377.0559	0	8193.284	0	4054.087	0	56.36116	3318.447	3535.531
2.51E+13	421.2781	0	10021.26	0	4820.726	0	66.72228	4266.253	4709.948
2.97E+13	534.7782	0	9808.202	0	5502.366	0	77.00006	5254.754	6894.95
3.3E+13	2333.335	451.6948	5710.532	1372.89	5320.032	1287.223	88.63896	7106.811	11703.98
3.93E+13	6169.56	3503.253	5890.532	3782.586	5023.337	3216.53	98.55563	7559.034	15205.79
4.59E+13	9129.507	7302.173	6800.505	5780.449	4919.476	4181.559	107.2779	7829.673	19159.6
5.47E+13	13783.23	11244.18	5494.671	4670.476	4486.42	3813.447	115.7779	8562.951	25465.74
6.35E+13	16816.37	13815.65	4486.754	3813.753	4045.531	3438.725	123.9445	8831.646	32767.25
7.28E+13	19390.27	16000.29	3598.281	3058.53	3384.614	2876.919	132.0557	8831.646	41331.03

8.24E+13	21325.93	17643.15	2851.808	2424.03	2801.558	2381.335	140.8334	8831.646	50648.37
1.81E+13	377.1947	0	7025.922	0	3706.531	0	53.94449	2895.725	3064.308
2.03E+13	377.0559	0	8193.284	0	4054.087	0	56.36116	3318.447	3535.531
2.51E+13	421.2781	0	10021.26	0	4820.726	0	66.72228	4266.253	4709.948
3.04E+13	490.0559	0	11216.26	0	5237.476	0	75.75006	5252.199	6464.394
3.27E+13	1367.529	0	8701.368	670.1116	5390.754	0	85.44451	6609.894	9341.007
3.61E+13	4423.309	371.1114	7523.7	3480.308	4738.865	1279.501	95.13897	7350.728	12140.51
4.27E+13	9122.063	4193.309	7351.367	6143.644	4084.614	2736.697	103.8056	7861.84	15774.35
4.68E+13	10627.18	8607.812	7489.867	6366.394	4143.976	3522.364	112.2779	8232.368	18837.49
5.26E+13	12802.95	10450.23	7679.645	6527.7	4120.253	3502.197	120.4723	8496.59	22616.71
5.98E+13	15178.04	12465.26	7438.117	6322.394	3995.809	3396.447	128.6112	8710.563	28016.08
6.88E+13	18061.85	14913.32	6510.116	5533.588	3717.336	3159.753	137.4446	8831.646	35349.58
1.81E+13	377.1947	0	7025.922	0	3706.531	0	53.94449	2895.725	3064.308
2.03E+13	377.0559	0	8193.284	0	4054.087	0	56.36116	3318.447	3535.531
2.51E+13	421.2781	0	10021.26	0	4820.726	0	66.72228	4266.253	4709.948
3.05E+13	485.5837	0	11365.37	0	5214.56	0	75.41673	5252.032	6438.477
3.36E+13	1231.751	0	10870.48	4.388892	5401.865	0	83.8334	6212.366	8556.118
3.68E+13	3655.031	0	10665.18	505.1671	5232.06	0	92.66674	6937.561	10672.06
4.01E+13	6355.616	0	11212.79	900.6674	4805.004	0	101.139	7138.589	12311.65
4.3E+13	9483.563	0	9813.869	3185.78	4266.253	213.3057	109.5834	7653.562	14579.29
4.67E+13	11483.68	549.6949	9747.258	6304.005	3753.059	1219.057	117.7501	7999.118	17363.6
5.17E+13	13134.7	2447.058	11005.73	9354.869	3506.058	1690.89	125.9723	8180.757	20153.21
5.81E+13	15621.18	4999.337	12258.65	10419.84	3306.614	2241.807	134.8334	8250.951	23334.41
1.81E+13	377.1947		7025.922		3706.531		53.94449	2895.725	3064.308
2.03E+13	377.0559		8257.423		4058.837		56.38893	3285.558	3502.781
2.55E+13	419.3059		11090.79		4805.337		67.25005	4064.031	4349.587
3.15E+13	474.5282		14671.01		5765.81		78.19451	4611.67	4991.671
3.7E+13	590.1116		18378.32		6455.061		89.13896	5355.893	5852.616
4.31E+13	876.2229		22649.91		7146.645		99.16675	6515.283	7136.589
4.79E+13	1264.001		26533.52		7286.561		108.2223	7276.45	8079.312
5.26E+13	1793.863		30846.55		7034.839		117.0834	7567.589	8582.59
5.75E+13	2322.891		35295.14		6722.561		125.7223	7839.09	9166.702
6.26E+13	2705.002		40001.64		6438.227		134.389	8000.423	9687.674
6.83E+13	3215.03		45130.7		6165.394		143.8057	8046.701	10185.65

2.18E+13	219.2355	0	8851.565	0	5099.782	0	68.09047	3441.928	3885.209
3.05E+13	387.1764	16.10508	12098.05	69.61463	7430.789	147.7737	469.7754	3616.626	6168.852
4.29E+13	1403.754	991.2701	8750.524	4143.541	8510.146	2467.423	1167.688	3795.765	11726.16
5.52E+13	2466.997	2316.027	7575.621	6841.286	8761.874	5068.132	1430.434	4058.205	16951.54
6.72E+13	3801.782	3781.28	7518	7456.047	8535.399	7263.131	1565.785	4403.956	22163.32
7.76E+13	5106.388	5104.963	6530.437	6525.892	8592.717	8428.123	1621.388	4749.599	26302.74
8.63E+13	6260.146	6260.085	4406.169	4406.068	7769.967	7749.748	1639.748	5094.836	31341.02
9.31E+13	7448.366	7448.364	1638.411	1638.41	5632.183	5615.573	1623.497	5441.199	37026.74
9.9E+13	9280.589	9280.589	354.5804	354.5804	3226.091	3210.286	1612.51	5786.946	45173.37
1.06E+14	15451.55	15451.55	60.05052	60.05052	1051.182	1041.388	1265.839	5959.822	50866.17

2.18E+13	219.2357	0	8851.565	0	5099.782	0	68.09053	3441.928	3885.209
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3.05E+13	387.1765	16.10515	12098.05	69.61465	7430.789	147.7737	469.7754	3616.626	6168.852
3.98E+13	775.3556	191.791	12208.5	1239.289	8691.784	1033.411	978.2611	3795.765	9686.158
4.98E+13	1319.627	733.1452	9533.9	3548.365	9428.595	2465.919	1282.377	4058.205	14564.38
5.99E+13	2118.197	1817.735	7093.653	5716.497	9196.849	4327.755	1456.892	4403.956	19841.83
6.92E+13	3082.727	3016.392	6458.481	6306.367	7961.908	6137.644	1546.93	4749.703	24850.26
7.86E+13	4313.255	4306.925	5640.559	5632.769	7189.472	6869.043	1561.718	5095.296	29411.76
8.63E+13	5450.96	5450.718	4442.959	4442.775	6585.706	6547.896	1521.411	5441.199	33729.41
9.24E+13	6487.219	6487.213	2118.904	2118.9	5068.597	5050.732	1477.904	5786.946	40148.88
9.79E+13	8077.171	8077.17	520.8316	520.8316	3115.661	3100.921	1398.719	5959.822	47834.02

2.18E+13	219.2357	0	8851.565	0	5099.782	0	68.09053	3441.928	3885.209
3.05E+13	387.1765	16.10515	12098.05	69.61465	7430.789	147.7737	469.7754	3616.626	6168.852
3.89E+13	674.4229	86.1546	13126.78	584.971	8887.909	686.4759	899.1416	3795.765	9002.652
4.76E+13	1025.062	275.3962	12302.61	1627.682	9729.048	1475.032	1157.488	4058.205	12882.94
5.61E+13	1459.29	789.6089	9348.662	3421.148	9915.125	2603.943	1337.083	4403.956	17606.35
6.39E+13	2020.774	1666.006	6562.178	4883.515	8493.513	4112.905	1475.188	4749.703	23200.4
7.24E+13	2913.208	2823.853	5480.565	5314.427	6981.686	5274.827	1522.486	5095.449	28294.21
7.52E+13	3162.278	3110.164	4830.65	4757.693	6325.379	5346.613	1391.703	5415.435	30148.63
7.79E+13	3432.781	3406.419	4468.341	4443.793	5665.795	5187.022	1273.387	5786.946	32335.9
8.16E+13	3925.137	3919.447	3730.861	3727.169	4879.808	4721.519	1204.465	5959.822	36910.03

2.18E+13	219.2357	0	8851.565	0	5099.782	0	68.09053	3441.928	3885.209
3.05E+13	387.1765	16.10515	12098.05	69.61465	7430.789	147.7737	469.7754	3616.626	6168.852
3.87E+13	598.0706	33.21328	14306.74	199.5145	9242.901	414.3176	810.7903	3795.765	8351.13
4.6E+13	827.7225	58.79766	15123.12	349.7812	10369.53	690.2669	990.6374	4058.205	11042.94
5.18E+13	1030.743	90.76764	15207.27	512.6693	11018.96	936.0508	1057.927	4403.956	13506.28
5.61E+13	1196.174	127.5328	15104.65	641.6572	9776.681	1186.072	1101.617	4749.703	16593.68
6.01E+13	1323.897	175.6812	14730.88	777.6026	8469.005	1236.969	1129.148	5095.449	19648.48
6.36E+13	1372.213	276.7975	11160.51	1045.26	7697.961	1414.241	1203.616	5441.199	24149.91
6.74E+13	1358.938	462.2371	7259.085	1407.141	6851.738	1707.83	1224.087	5786.946	29450.69
7.16E+13	1335.447	819.4257	3516.147	1851.386	5957.455	2205.975	1192.915	5959.822	35677.9
1.86E+13	142.5806	0	7484.868	0	4020.804	0	58.20096	2933.274	3099.994
2.18E+13	219.2357	0	8851.565	0	5099.782	0	68.09053	3441.928	3885.209
3.08E+13	368.2873	0	12485.38	0	7693.43	0	453.3049	3616.626	5968.163
3.91E+13	581.0001	0	14807.67	0	9496.692	0	787.0885	3795.765	8166.085
4.63E+13	787.8785	0	15825.5	0	10762.64	0	956.7709	4058.205	10702.96
5.2E+13	962.4356	0	16169.4	0	11566.52	0	1012.887	4403.956	13009.09
5.59E+13	1105.801	0	16335.46	0	10509.02	0	1039.765	4749.703	15647.65
5.92E+13	1236.26	0	16468.2	0	9235.78	0	1034.629	5095.449	18092
6.16E+13	1294.204	0	13751.89	0	8709.46	0	1063.596	5441.199	21361.13
6.34E+13	1280.409	0	11783.17	0	8193.442	0	1045.101	5786.946	24441.55
6.49E+13	1185.687	0	10185.39	0	8134.335	0	992.6888	5959.822	27340.7
1.84E+13	96.38897	0	7419.45	0	3805.559	0	60.91672	2969.447	3138.891
2.15E+13	139.4723	0	8505.562	0	5152.782	0	91.02785	3144.447	3786.114
2.92E+13	184.0557	0.083333	8488.896	0.222222	11444.45	0.083333	112.8056	2988.891	4888.893
3.33E+13	490.5559	307.2225	4255.559	0.305556	14441.68	275.778	262.2224	3686.114	7858.34
4.46E+13	3091.669	2952.78	878.0563	0.333334	8883.34	1625.557	337.2225	7633.339	20308.35

6.99E+13	6316.672	6247.227	3.944448	0.277778	4672.226	1988.057	340.5558	10950.01	42777.81
9.7E+13	7533.339	7511.117	1.583335	0.25	2760.558	2015.002	333.3336	12011.12	68083.39
1.21E+14	8350.007	8344.451	0.444445	0.222222	1697.501	1397.501	317.5003	12402.79	90750.07
1.42E+14	9113.896	9108.341	0.555556	0.222222	623.0561	490.2782	311.3891	12733.34	112416.8
1.62E+14	9294.452	9291.674	0.583334	0.222222	293.8891	198.0279	309.7225	13027.79	133611.2
1.78E+14	9305.563	9302.785	0.527778	0.222222	96.02785	22.44446	311.1114	13230.57	150750.1
1.84E+13	96.38897	0	7419.45	0	3805.559	0	60.91672	2969.447	3138.891
2.15E+13	139.4723	0	8505.562	0	5152.782	0	91.02785	3144.447	3786.114
2.92E+13	184.0557	0.083333	8488.896	0.222222	11444.45	0.083333	112.8056	2988.891	4888.893
3.75E+13	318.6114	52.44449	4611.115	1.222223	21275.02	590.2783	224.7224	3169.447	6166.672
4.75E+13	1011.39	588.6116	1219.445	4.333337	25872.24	6336.116	306.1114	4994.448	11241.68
6.38E+13	2802.78	2427.224	14.19446	5.361115	23777.8	12822.23	333.3336	8391.673	23888.91
8.52E+13	4866.671	4566.67	7.19445	4.888893	19011.13	14080.57	342.2225	10758.34	43805.59
1.09E+14	5733.338	5525.004	3.944448	3.750003	14311.12	12036.12	338.3336	11980.57	69111.17
1.32E+14	6566.672	6450.005	2.027779	1.694446	7172.228	6494.45	333.6114	12336.12	97222.3
1.55E+14	8091.673	7897.229	0.694445	0.333334	3027.78	2739.724	324.1669	12513.9	124722.3
1.73E+14	9247.23	8911.118	0.527778	0.222222	1561.668	1405.834	318.0558	12663.9	144250.1
1.84E+13	96.38897	0	7419.45	0	3805.559	0	60.91672	2969.447	3138.891
2.15E+13	139.4723	0	8505.562	0	5152.782	0	91.02785	3144.447	3786.114
2.92E+13	184.0557	0.083333	8488.896	0.222222	11444.45	0.083333	112.8056	2988.891	4888.893
3.93E+13	262.2224	19.83335	5405.56	26.63891	23297.24	427.5003	213.2502	3002.78	5652.782
4.99E+13	553.056	197.9446	2146.113	162.9446	32750.03	5341.671	286.6669	4027.781	8219.451
6.46E+13	1145.279	741.6673	682.5005	273.028	37583.36	18475.01	316.9447	6533.339	15650.01
8.17E+13	2321.669	1978.89	283.3336	267.2502	35583.36	23963.91	333.3336	9261.119	30055.58
1E+14	3569.447	3311.114	223.0557	222.8057	27391.69	22175.02	342.2225	10994.45	51694.49
1.23E+14	4808.337	4669.448	131.4445	131.139	17019.46	14916.68	342.2225	12008.34	80583.4
1.45E+14	6550.005	6516.672	48.94448	48.61115	7594.451	6838.894	338.0558	12319.45	110194.5
1.63E+14	7730.562	7725.006	43.69448	43.4167	4513.893	4180.559	342.2225	12452.79	132361.2
1.84E+13	96.38897	0	7419.45	0	3805.559	0	60.91672	2969.447	3138.891
2.15E+13	139.4723	0	8505.562	0	5152.782	0	91.02785	3144.447	3786.114
2.92E+13	184.0557	0.083333	8488.896	0.222222	11444.45	0.083333	112.8056	2988.891	4888.893
3.96E+13	294.4447	15.3889	5763.894	58.72227	23275.02	235.2502	209.6668	2972.225	5600.004
5.03E+13	757.7784	153.1668	3163.891	472.2226	32722.25	2733.613	280.278	3830.559	7658.339
6.41E+13	1582.501	605.8338	2360.835	1353.057	37833.36	10938.9	311.1114	5980.56	13125.01
7.88E+13	2517.224	1506.946	1921.946	1793.613	37583.36	18616.68	328.0558	8550.007	23636.13
9.43E+13	3261.114	2368.891	1859.724	1858.89	33111.14	20044.46	339.4447	10105.56	39638.92
1.12E+14	3558.336	2944.447	1843.89	1843.613	26155.58	17605.57	342.2225	11272.23	61972.27
1.29E+14	3619.447	3325.003	1970.557	1970.279	18425.01	13872.23	338.3336	11938.9	85666.74
1.39E+14	3516.669	3363.892	2443.335	2443.058	13500.01	11402.79	342.2225	12197.23	102333.4
1.84E+13	96.38897	0	7419.45	0	3805.559	0	60.91672	2969.447	3138.891
2.15E+13	139.4723	0	8505.562	0	5152.782	0	91.02785	3144.447	3786.114
2.92E+13	184.0557	0.083333	8488.896	0.222222	11444.45	0.083333	112.8056	2988.891	4888.893
4.08E+13	260.028	2.250002	8188.895	14.50001	22897.24	6.888894	193.4168	2844.447	5272.226
5.31E+13	542.7782	20.50002	7744.451	158.7779	34361.14	107.139	256.1946	3150.003	6016.671
6.59E+13	1143.89	81.05562	7125.006	701.3895	42694.48	710.0006	298.8891	4483.337	8744.451
7.64E+13	1934.446	189.6113	6458.339	1758.335	43277.81	2729.447	321.3891	6833.339	14950.01
8.71E+13	2587.224	336.3892	5227.782	2750.836	37583.36	5658.338	334.7225	8766.674	26447.24

1.01E+14	2911.113	525.2782	4277.781	3480.558	29638.91	7827.784	342.2225	10088.9	43388.92
1.17E+14	3047.225	777.2228	4333.337	4244.448	21852.8	7708.34	340.2781	11275.01	65138.94
1.28E+14	3327.78	1040.556	4380.559	4372.226	14102.79	5383.338	342.2225	12183.34	85055.62
1.84E+13	96.38897	0	7419.45	0	3805.559	0	60.91672	2969.447	3138.891
2.15E+13	139.4723	0	8505.562	0	5152.782	0	91.02785	3144.447	3786.114
2.98E+13	177.7779	0	10330.56	0	10308.34	0	100.3334	2936.113	4750.004
4.12E+13	237.7502	0	14594.46	0	17905.57	0	139.389	2641.669	4661.115
5.57E+13	474.7226	0	21363.91	0	26491.69	0	182.3057	2461.669	4355.559
7.04E+13	908.8896	0	28750.02	0	32888.92	0	246.3613	2755.28	5413.893
8.27E+13	1391.668	0	35805.58	0	35305.58	0	281.1113	3888.892	8466.673
9.33E+13	1925.279	0	40861.14	0	35722.25	0	303.8891	5775.005	13397.23
1.04E+14	2472.78	0	42666.7	0	34972.25	0	322.778	7852.784	21350.02
1.15E+14	2966.669	0	40916.7	0	31833.36	0	333.0558	9100.007	34138.92
1.25E+14	3383.336	0	36472.25	0	25583.35	0	342.2225	9997.23	50111.15

Secondary electricity (nuclear)	Secondary electricity (oil)	Secondary electricity (solar)	Secondary electricity (wind)	Secondary electricity (gas)	Secondary electricity (heat)	Secondary electricity (heat, kWh)	Secondary electricity (heat, hydro)	Secondary electricity (hydrogen)	Secondary electricity (biofuels)
2767.954	1169.036	4.572004	103.8741	14632.81				2.06E-06	310.3908
2756.29	970.6147	33.72603	341.3472	15088.05				0.000467	450.9987
2853.655	714.718	501.432	1274.182	16039.61				4.130446	604.8693
3003.408	1270.106	894.0599	1580.499	15204.95				1952.01	3257.076
2227.568	108.0643	7705.728	4643.847	15747.12				11149.98	5402.312
1016.863	19.6495	14550.4	8976.504	15049.48				15180.77	6619.99
871.7987	17.21555	20102.12	9079.61	13186.74				15075.55	7881.239
960.1889	20.2861	24064.44	6949.914	10885.3				15191.19	8979.176
1182.995	19.10052	27538.17	7144.408	8630.86				16417.24	9301.824
1464.955	15.01467	29251.03	8525.601	7354.334				18611.88	8693.829
1359.365	11.68999	28607.46	7745.816	6714.7				21688.68	7742.769
2767.954	1169.036	4.572004	103.8741	14632.81				2.06E-06	310.3908
2756.29	970.6148	33.72603	341.3472	15088.04				0.000467	450.9987
2919.105	925.7539	443.5454	1217.251	18417.54				3.38498	587.2743
3060.619	670.252	1573.757	2573.899	23071.78				246.1763	1214.938
2363.34	310.4542	5877.013	4507.725	27958.41				884.1898	2415.569
1084.737	25.1396	13727.54	6884.548	29122.11				1312.588	3576.635
785.5809	9.147158	21126.19	8349.753	27758.91				2607.202	5454.636
588.911	6.972237	26891.01	8692.266	24164.74				5302.921	7074.238
571.7749	4.882377	30061.93	8488.715	18862.07				11931.13	8662.597
689.0964	2.156668	29892.49	7339.472	14644.86				19110.82	9110.517
701.5105	2.24679	36065.02	7491.048	13755.99				19605.88	9641.607
2767.954	1169.036	4.572004	103.8741	14632.81				2.06E-06	310.3908
2756.29	970.6148	33.72603	341.3472	15088.04				0.000467	450.9987
2934.539	971.9464	441.6745	1212.521	18959.58				3.637269	660.8523
2999.972	695.5865	1255.332	2318.242	25216.47				252.4657	1470.111
2177.351	293.0182	4075.835	4432.16	32381.58				894.3471	2477.306
947.3177	34.49674	10943.8	7348.7	35513.36				1043.107	3562.003
619.5147	13.21136	19221.92	8390.584	35455.67				1582.929	5439.097
376.1914	8.4563	27837.25	9291.283	31213.8				2616.383	8153.651
236.2891	5.973506	33034.18	10124.69	23939.9				5817.84	11501.96
278.8533	2.585592	32753.65	9478.941	16058.9				13224.83	13329.9
335	1.4967	34154.81	8483.827	12337.23				18480.53	13262.38
2767.954	1169.036	4.572004	103.8741	14632.81				2.06E-06	310.3908
2756.29	970.6148	33.72603	341.3472	15088.04				0.000467	450.9987
2935.636	966.6882	441.0525	1211.584	18852.5				3.638303	731.9533
2991.8	699.9401	1190.635	2230.372	25716.46				248.912	1743.307

2134.499	263.1485	3408.364	4149.557	34343.5					927.5407	2966.112
882.8207	35.22019	8744.843	6938.647	38281.28					1140.24	3896.643
528.5068	9.361046	15052.04	8158.573	39255.53					1565.575	5416.825
264.2906	8.562074	24693.96	8656.121	36450.33					2383.835	8032.827
95.19405	5.825642	32457.38	9828.113	31419.8					3418.25	11723.35
122.8914	3.758593	35465.61	10557.82	24951.27					4629.901	14361.42
135.8148	1.769752	36075.82	10104.71	19391.44					6148.672	15484.48
2767.954	1169.036	4.572004	103.8741	14632.81					2.06E-06	310.3908
2756.29	970.6148	33.72603	341.3472	15088.04					0.000467	450.9987
2936.33	971.3585	440.7903	1211.108	18869.04					3.639259	737.9254
2991.614	694.1699	1174.396	2203.281	25602.83					248.4919	1766.173
2125.479	230.7258	3268.148	4079.149	34794					941.7019	2993.77
869.3021	36.25816	8196.23	6782.169	39286.62					1167.757	3833.785
509.669	8.291322	13762.04	7916.809	40852.12					1613.034	5218.332
236.7996	7.553277	21682.33	8358.948	39416.23					2505.83	7825.962
57.27229	5.171442	30379.08	9201.48	36026.22					3717.738	11259.95
51.59282	3.202655	34647.04	9291.638	31649.91					5143.251	13399.21
35.60531	1.421025	34914.69	8941.338	27420.28					6476.389	14066.17
2723.613	1112.223	4.16667	106.389	24290.02	3730.559	3.73E+12	41.6667	0	258.8891	
2712.224	679.7228	68.88894	460.2781	26177.24	3680.003	3.68E+12	52.77782	55.00004	666.6672	
3394.169	310.8336	440.0004	1856.668	29605.3	4021.67	4.02E+12	78.61117	0	950.0008	
5209.726	166.9446	2176.946	6559.172	32829.75	6281.394	6.28E+12	143.889	1363.89	1109.723	
8635.562	73.88895	4585.281	13941.96	32368.36	7428.061	7.43E+12	263.0558	5577.227	2838.058	
15917.51	26.38891	8818.896	19836.68	28032.52	7192.784	7.19E+12	443.3337	11352.51	4503.892	
26571.41	6.94445	13593.07	25383.35	20881.41	5898.616	5.9E+12	713.8895	15963.35	8450.84	
32352.53	0	20179.46	32781.97	13001.4	5545.838	5.55E+12	855.0007	17786.96	14830.57	
33363.36	0	25323.63	41065.03	8964.174	6122.783	6.12E+12	1031.667	17972.24	18624.74	
29788.63	0	32780.03	49257.54	6489.172	6783.617	6.78E+12	1171.39	16933.35	21087.24	
21306.13	0	44380.04	59210.33	6169.727	7362.784	7.36E+12	1358.89	16669.74	21825.85	
2723.336	1111.668	4.16667	107.5001	24287.24	3732.225	3.73E+12	41.6667	0	258.8891	
2711.947	679.7228	68.88894	461.3893	26284.19	3680.003	3.68E+12	52.77782	60.5556	645.0005	
3444.169	311.3891	440.0004	1853.057	29655.02	4247.226	4.25E+12	78.61117	0	995.0008	
4888.337	169.7224	640.2783	4671.393	35362.53	6058.338	6.06E+12	99.44452	464.4448	836.9451	
7020.283	75.27784	1456.946	7874.729	42116.7	7136.395	7.14E+12	57.77782	2118.613	2005.002	
11575.56	26.11113	3510.836	11325.01	45774.48	8505.84	8.51E+12	69.4445	6535.283	3464.725	
18166.4	6.666672	6378.338	15277.79	45951.7	9736.674	9.74E+12	102.7779	14044.18	5545.56	
25545.58	0	11267.51	20407.79	39771.7	8978.618	8.98E+12	150.5557	24048.35	9530.285	
29928.64	0	16898.9	29787.8	31921.14	9186.118	9.19E+12	269.1669	27235.58	13415.84	
31823.08	0	24593.63	42954.76	22714.74	8708.618	8.71E+12	421.9448	26946.13	16648.07	
29988.91	0	36395.58	58303.94	15219.73	8909.452	8.91E+12	637.5005	26440.58	18721.68	
2723.336	1111.668	4.16667	107.5001	24287.24	3732.225	3.73E+12	41.6667	0	258.8891	
2711.947	679.7228	68.88894	461.3893	26284.19	3679.725	3.68E+12	52.77782	60.5556	645.0005	
3446.669	311.6669	440.0004	1842.224	29907.52	4116.948	4.12E+12	78.61117	0	993.8897	
3524.169	171.389	515.8337	3685.003	36396.14	5474.727	5.47E+12	97.50008	128.6112	471.3893	
4126.392	76.11117	898.0563	6665.005	44886.42	6021.671	6.02E+12	29.72225	866.9451	642.7783	
6314.449	26.66669	2015.279	10070.84	52916.71	6258.894	6.26E+12	29.72225	2785.836	1524.723	
11500.29	6.94445	4293.337	13736.96	56502.27	6660.283	6.66E+12	33.61114	6789.45	3208.058	

20382.79	0	6919.172	16833.35	54315.88	8646.396	8.65E+12	35.83336	14516.96	6368.338
27893.36	0	9959.175	20825.57	54305.04	11795.29	1.18E+13	56.66671	24464.74	9375.008
32636.41	0	15871.12	29874.47	46031.15	12613.62	1.26E+13	86.94451	31277.53	11865.57
35974.75	0	22152.8	42077.26	38055.59	12658.34	1.27E+13	128.0557	34545.86	14967.23
2723.336	1111.668	4.16667	107.5001	24287.24	3732.225	3.73E+12	41.6667	0	258.8891
2712.224	679.7228	68.88894	461.3893	26284.47	3679.725	3.68E+12	52.77782	60.5556	645.0005
3448.336	311.9447	440.0004	1665.557	29965.86	4040.003	4.04E+12	78.61117	0	975.2786
3311.392	171.6668	467.5004	3625.558	36450.31	5356.949	5.36E+12	97.50008	35.55558	431.667
3148.336	76.94451	635.0005	6074.449	45105.59	5099.171	5.1E+12	29.72225	506.6671	287.5002
4546.67	26.94447	1177.223	8940.285	53838.65	5053.615	5.05E+12	29.72225	1302.501	798.6118
7256.117	6.94445	2323.335	13221.12	61069.77	5765.838	5.77E+12	29.72225	3158.891	1445.001
13436.4	0	4750.559	16448.9	63741.72	7648.617	7.65E+12	20.00002	7042.506	2588.891
23190.3	0	7080.839	18918.63	65629.5	9550.008	9.55E+12	24.72224	14348.07	5105.282
35133.08	0	11529.18	21806.13	57218.1	11612.51	1.16E+13	24.72224	25247.24	7852.229
41283.92	0	15449.46	28912.52	50285.04	13869.73	1.39E+13	35.00003	39006.98	10218.34
2723.336	1111.668	4.16667	107.5001	24287.24	3732.225	3.73E+12	41.6667	0	258.8891
2712.224	679.7228	68.88894	461.3893	26284.47	3679.725	3.68E+12	52.77782	60.5556	645.0005
3435.558	311.9447	440.0004	1630.279	29763.63	3998.892	4E+12	78.61117	0	985.2786
3080.836	172.5001	453.6115	3245.28	36388.36	4752.504	4.75E+12	97.50008	0	448.0559
2114.168	77.50006	473.0559	5197.226	44580.31	4118.892	4.12E+12	29.72225	174.4446	260.278
1727.779	27.22224	550.8338	7971.951	53845.6	3723.336	3.72E+12	29.72225	685.5561	634.445
2930.558	6.94445	1178.89	11746.4	62267.55	3874.448	3.87E+12	29.16669	1105.279	988.3341
5298.893	0	2595.835	15788.9	68841.44	5587.782	5.59E+12	8.888896	1906.113	1200.557
10364.45	0	4669.448	19493.35	69853.67	7883.062	7.88E+12	12.77779	3392.78	1195.834
15652.79	0	7532.784	22352.24	66751.16	11211.95	1.12E+13	13.05557	7195.284	1281.112
24982.24	0	10192.51	23448.35	59086.44	12453.07	1.25E+13	13.8889	10916.12	948.6119
2723.336	1111.668	4.16667	107.5001	24287.24	3732.225	3.73E+12	41.6667	0	258.8891
2712.224	679.7228	68.88894	461.3893	26285.85	3679.725	3.68E+12	52.77782	60.5556	645.0005
3266.947	311.1114	440.0004	1528.89	30271.14	3774.17	3.77E+12	78.61117	0	948.8896
3041.947	173.3335	447.7781	2849.447	36527.25	4190.003	4.19E+12	97.50008	0	466.3893
1985.279	78.05562	405.2781	4630.281	43617.53	3564.725	3.56E+12	29.72225	175.5557	245.278
1186.112	27.22224	285.8336	6837.505	52493.1	3294.725	3.29E+12	29.72225	688.6117	660.0005
1556.39	7.222228	687.2228	9982.23	60643.1	3370.28	3.37E+12	29.72225	1023.056	924.4452
2711.669	0	1603.612	13579.46	65351.44	3961.67	3.96E+12	9.166674	1683.335	873.334
4771.67	0	2383.613	15629.73	65857.83	5550.282	5.55E+12	9.166674	3871.114	1120.279
8216.118	0	3725.281	18958.07	63204.5	8949.729	8.95E+12	9.166674	8113.34	1696.39
12345.84	0	5963.616	23475.02	63530.61	10585.56	1.06E+13	2.77778	9883.063	1734.168
2737.724	1158.751	2.833336	102.139	15226.87	3688.364	3.69E+12	3.555558		0
2805.613	1306.557	26.00002	125.139	16397.68	4098.614	4.1E+12	3.500003		94.25008
3514.419	1615.39	58.66671	307.7502	21070.74	4981.365	4.98E+12	3.888892		280.0002
5234.199	1730.501	295.4725	1256.084	25359.05	5745.06	5.75E+12	4.472226		700.5561
5958.949	2005.446	1293.557	3202.503	21784.02	5029.004	5.03E+12	4.833337		1536.057
5074.976	1914.724	2695.391	4839.754	21866.32	4658.198	4.66E+12	5.083337		2501.974
4059.587	1798.029	4021.864	7187.422	21493.43	4620.254	4.62E+12	5.30556		3815.947
3885.198	1632.307	5805.755	10967.65	18478.26	3925.67	3.93E+12	5.527782		5673.81
3898.059	1503.335	8530.868	15267.26	15660.79	3445.753	3.45E+12	5.722227		7449.867
3840.614	1295.64	11724.87	20629.1	13221.98	3006.919	3.01E+12	5.833338		9015.424

3692.947	1083.945	15502.9	26159.83	11369.7	2606.697	2.61E+12	5.944449	10256.95
2737.724	1158.751	2.833336	102.139	15226.87	3688.364	3.69E+12	3.555558	0
2805.613	1306.557	26.00002	125.139	16397.68	4098.614	4.1E+12	3.500003	94.25008
3514.419	1615.39	58.66671	307.7502	21070.74	4981.365	4.98E+12	3.888892	280.0002
5224.476	1745.251	223.9446	901.4174	26090.3	5734.671	5.73E+12	4.388892	594.556
5837.699	2055.363	734.5006	1900.113	27198.47	5593.282	5.59E+12	4.694448	1100.112
5422.865	1807.363	1635.668	3047.502	29077.3	4884.476	4.88E+12	4.916671	1763.251
4886.004	1489.946	2795.724	5001.226	27945.61	4387.031	4.39E+12	5.138893	2837.058
4233.142	1508.168	3711.781	6769.117	28782.72	4339.281	4.34E+12	5.388893	3930.086
3848.17	1526.723	4841.782	9145.98	28519.55	4246.003	4.25E+12	5.583338	5175.421
3630.92	1526.112	6627.644	12537.45	26805.1	4063.059	4.06E+12	5.694449	6780.922
3672.892	1479.112	9305.813	17063.1	23532.49	3762.059	3.76E+12	5.777782	8480.812
2737.724	1158.751	2.833336	102.139	15226.87	3688.364	3.69E+12	3.555558	0
2805.613	1306.557	26.00002	125.139	16397.68	4098.614	4.1E+12	3.500003	94.25008
3514.419	1615.39	58.66671	307.7502	21070.74	4981.365	4.98E+12	3.888892	280.0002
5223.81	1744.279	219.6946	880.3896	26110.83	5733.532	5.73E+12	4.388892	588.7782
5521.671	2018.307	619.2505	1630.029	28848.47	5914.588	5.91E+12	4.694448	1011.529
4668.17	1949.696	1255.807	2375.53	31975.78	5551.643	5.55E+12	4.888893	1563.279
3659.142	1724.612	1801.168	3259.947	36526.08	5089.56	5.09E+12	5.111115	2200.141
3233.725	1581.973	2421.446	4383.726	39342.64	4439.781	4.44E+12	5.333338	2960.752
2942.197	1435.973	3278.308	5957.449	41228.87	4150.198	4.15E+12	5.527782	3686.281
2523.585	1384.779	4154.809	7680.867	43310.7	4113.503	4.11E+12	5.638893	4375.726
2212.474	1324.529	5145.032	9792.952	44845.2	4074.281	4.07E+12	5.750005	5181.643
2737.724	1158.751	2.833336	102.139	15226.87	3688.364	3.69E+12	3.555558	0
2755.28	1306.39	25.83335	125.4723	16410.85	4109.809	4.11E+12	3.500003	94.66674
3216.669	1617.835	42.50003	165.2501	21146.71	5103.504	5.1E+12	4.222226	272.278
3633.781	1917.557	72.63895	217.5002	26316.05	6194.366	6.19E+12	4.805559	572.6671
3527.142	2190.53	117.9723	277.1669	30397.39	7095.256	7.1E+12	5.222226	986.0008
3035.002	2301.585	178.6946	330.4169	34280.92	7658.978	7.66E+12	5.472227	1531.057
2512.808	2242.085	237.2502	444.0281	38747	7757.923	7.76E+12	5.722227	2158.196
2099.002	2261.835	305.528	578.7782	42221.17	7847.173	7.85E+12	5.972227	2837.252
1736.779	2258.391	409.3614	778.9728	45548.51	7936.145	7.94E+12	6.166672	3402.808
1447.251	2338.113	529.1671	1010.279	48751.12	7985.09	7.99E+12	6.305561	3926.364
1264.057	2300.891	678.9172	1303.029	52080.99	8071.368	8.07E+12	6.416672	4560.587

2756.29	962.6616	33.4737	341.7173	31372.33	0	4.743809
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12062.67	495.3871	1612.895	5149.813	38272.99	309.2326	5008.146
19024.35	402.1292	3529.754	7933.148	38598.58	622.6292	8194.759
24865.73	352.5184	6318.113	9875.47	36486.16	1041.756	11457.28
30787.95	324.5241	9835.376	10096.38	34063.54	1477.217	17422.56
36171.18	345.8477	13577.58	11028.85	29682.37	2087.28	23990.59
40868.16	473.147	17430.34	12531.71	23139.31	2790.234	30295.74
40283.9	696.9083	22819.56	14954.36	16692.8	3572.181	35551.17
38580.64	447.0176	27581.92	16058.59	11293.21	4400.869	38069.71

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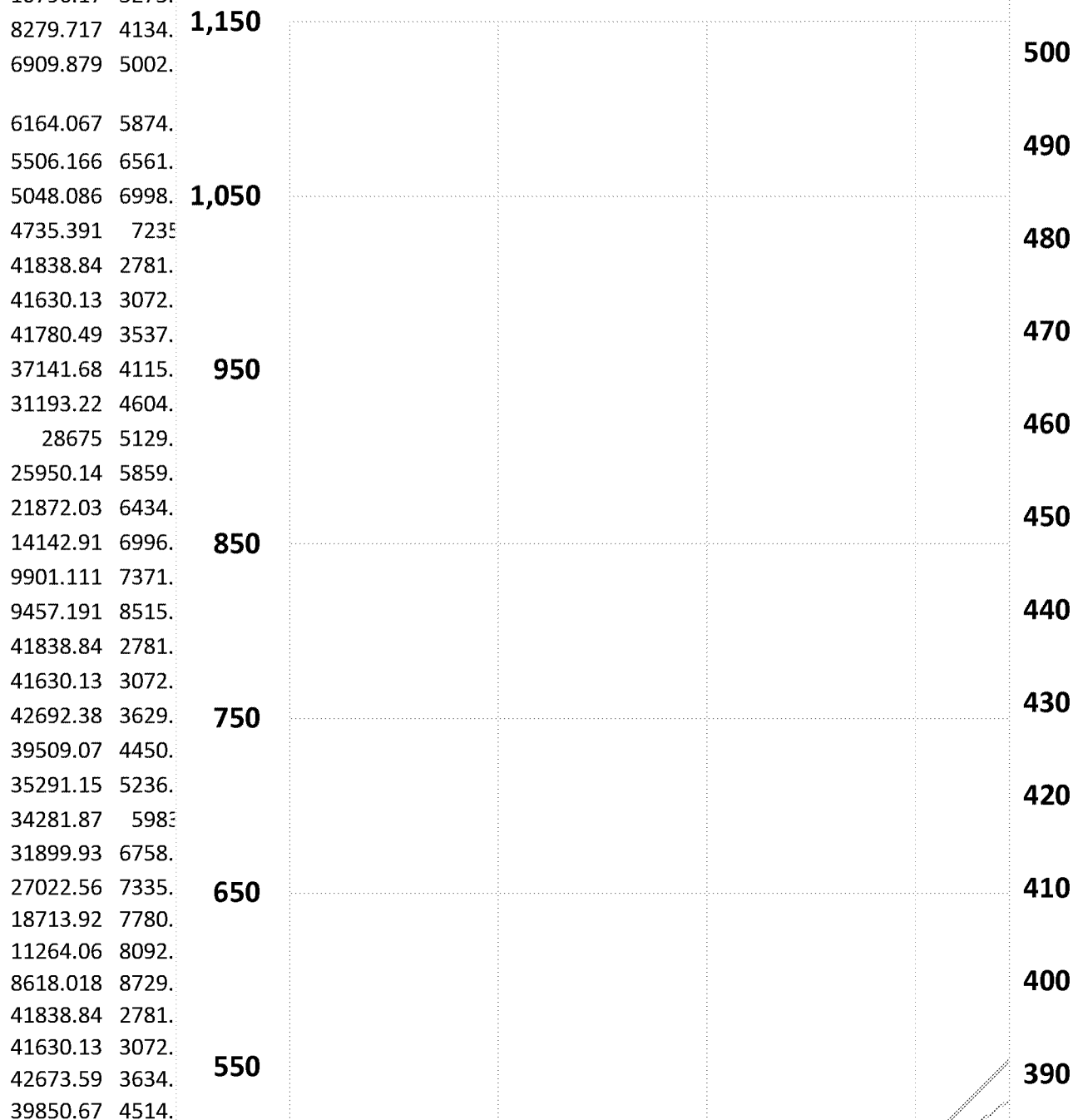
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21301.06	362.177	5494.082	8486.905	41545.36					909.3174	7267.178
26546.2	348.6297	8860.824	9692.804	37694.45					1247.838	11059.67
31726.84	301.4631	12579.8	10174.95	33641.05					1686.4	15933.67
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4027.688	422.122	487.8533	1594.598	37179.6					92.31782	1350.721
6728.393	472.5016	1158.853	3148.892	42506.05					281.8349	3132.603
11291.36	410.5575	2531.949	5135.303	44882.41					535.0667	4664.952
17365.04	356.4485	4779.242	7086.068	44813.42					853.0958	5878.719
23235.91	384.3106	8038.288	8937.223	41117.42					1141.117	8185.999
28368.33	322.0475	11758.94	9917.334	36483.28					1499.086	11132.5
30553.85	210.2796	14010.53	9330.96	36114.32					1733.124	12537.85
31731.46	231.8306	16120.34	9155.227	35116.07					1919.49	13364.65
31935.89	220.8236	19593.02	10152.73	32758.79					2094.911	15730.18
2756.29	962.6615	33.47343	341.7174	31372.33					0	4.743809
4027.688	422.122	487.8533	1594.598	37179.6					92.31782	1350.721
5735.447	493.349	1006.801	2737.774	44065.69					282.7679	2498.924
8219.01	420.0601	2032.219	3961.883	47422.28					535.3603	3350.476
10724.9	350.0077	3510.729	4533.673	48720.31					837.096	4031.254
13069.57	402.0175	5512.246	5230.114	45983.14					1056.85	5149.95
15564.6	361.7274	7717.294	5706.592	43019.42					1280.033	5595.287
18857.5	370.2286	10418.8	7086.295	41110.58					1479.184	6233.896
22109.21	371.706	13768.81	8670.85	39594.46					1669.476	7125.473
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7765.958	445.5765	1943.509	3744.478	47890.06					541.7462	3785.734
9948.332	376.9723	3306.326	4285.926	49375.11					850.5723	4513.282
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17651.61	402.9564	13167.79	7220.4	39103.11					1853.531	6889.162
2811.113	1126.112	1.722224	106.9445	15644.46	3627.781	3.63E+12	0	96.36119	0	
2830.558	1113.334	65.72227	483.8893	17208.35	3411.114	3.41E+12	0.027778	108.889	60.33338	
3377.78	803.334	458.6115	1328.334	22319.46	3366.669	3.37E+12	0.027778	132.5557	1175.834	
5822.227	383.0559	931.9452	2975.002	14791.68	2445.835	2.45E+12	104.0279	455.2781	1488.335	
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16086.12	0.055556	18077.79	13405.57	7225.006	4355.559	4.36E+12	4063.892	9500.008	22552.8
18630.57	0.027778	36555.58	19175.02	4744.448	7572.228	7.57E+12	7491.673	11261.12	27102.8
19997.24	0.027778	54222.27	23825.02	2687.224	10444.45	1.04E+13	10422.23	12841.68	28305.58
19683.35	0.027778	71250.06	28111.13	1365.001	11888.9	1.19E+13	11866.68	15172.23	29000.02
18658.35	0.027778	87777.85	32472.25	980.2786	12208.34	1.22E+13	12188.9	17366.68	28361.13
17413.9	0.027778	102861.2	34361.14	509.7226	12475.01	1.25E+13	12463.9	18930.57	28638.91
2811.113	1126.112	1.722224	106.9445	15644.46	3627.781	3.63E+12	0	96.36119	0
2830.558	1113.334	65.72227	483.8893	17208.35	3411.114	3.41E+12	0.027778	108.889	60.33338
3377.78	803.334	458.6115	1328.334	22319.46	3366.669	3.37E+12	0.027778	132.5557	1175.834
4775.004	383.0559	515.2782	2257.78	20388.91	3208.336	3.21E+12	6.472227	213.9724	1205.557
8122.229	0.027778	1408.612	4533.337	18472.24	3188.891	3.19E+12	159.8057	960.2785	3555.558
13272.23	0.027778	6366.672	8797.229	18636.13	3038.891	3.04E+12	1037.779	2571.669	16463.9
17527.79	0.027778	18850.02	13844.46	16175.01	4652.782	4.65E+12	3486.114	4313.892	31250.03
20250.02	0.027778	37555.59	19216.68	15522.23	7866.673	7.87E+12	7133.339	6377.783	36305.58
21152.79	0.027778	59833.38	24741.69	12777.79	10963.9	1.1E+13	10680.56	9902.786	38055.59
19611.13	0.027778	81166.73	30722.25	5277.782	13616.68	1.36E+13	13561.12	13519.46	36833.36
17522.24	0.027778	97944.52	33305.58	1788.057	14972.23	1.5E+13	14922.23	16419.46	35527.81
2811.113	1126.112	1.722224	106.9445	15644.46	3627.781	3.63E+12	0	96.36119	0
2830.558	1113.334	65.72227	483.8893	17208.35	3411.114	3.41E+12	0.027778	108.889	60.33338
3377.78	803.334	458.6115	1328.334	22319.46	3366.669	3.37E+12	0.027778	132.5557	1175.834
4313.892	383.0559	445.2781	1991.113	22408.35	3725.003	3.73E+12	0.527778	202.8613	1026.39
6180.561	0.027778	602.7783	3300.003	24150.02	3758.336	3.76E+12	44.9167	651.6672	1088.056
9500.008	0.027778	2442.78	6355.561	25830.58	3577.781	3.58E+12	435.2781	1696.946	4869.448
13455.57	0.027778	9991.675	10480.56	26138.91	3563.892	3.56E+12	1766.39	3086.114	13713.9
17266.68	0.027778	25047.24	15316.68	28861.13	5375.004	5.38E+12	4447.226	4702.782	23005.57
20238.91	0.027778	46944.48	21272.24	25208.35	8280.562	8.28E+12	7805.562	7102.783	30888.91
20563.91	0.027778	69722.28	27833.36	17405.57	11961.12	1.2E+13	11830.57	10527.79	36527.81
18538.9	0.027778	88527.85	31027.8	12513.9	15105.57	1.51E+13	15066.68	13119.45	36722.25
2811.113	1126.112	1.722224	106.9445	15644.46	3627.781	3.63E+12	0	96.36119	0
2830.558	1113.334	65.72227	483.8893	17208.35	3411.114	3.41E+12	0.027778	108.889	60.33338
3377.78	803.334	458.6115	1328.334	22319.46	3366.669	3.37E+12	0.027778	132.5557	1175.834
4250.003	383.0559	436.3892	1982.502	22425.02	3763.892	3.76E+12	0.333334	195.8613	1032.223
5947.227	0.027778	428.3337	3119.447	25838.91	4261.115	4.26E+12	11.69445	536.6671	1012.223
9158.341	0.027778	1224.723	5608.338	30277.8	4625.004	4.63E+12	138.2223	1255.279	4202.781
13172.23	0.027778	5847.227	8911.118	33111.14	4361.115	4.36E+12	653.8894	1883.335	10641.68
16402.79	0.027778	16250.01	12938.9	40250.03	4447.226	4.45E+12	1818.335	2471.113	16819.46
18602.79	0.027778	32500.03	17861.13	43944.48	5355.56	5.36E+12	3586.114	3644.447	20986.13
18944.46	0.027778	50027.82	23358.35	40583.37	7033.339	7.03E+12	6050.005	6116.672	23758.35
17461.13	0.027778	63555.61	26236.13	45111.15	8325.007	8.33E+12	7761.117	8075.006	24030.57
2811.113	1126.112	1.722224	106.9445	15644.46	3627.781	3.63E+12	0	96.36119	0
2830.558	1113.334	65.72227	483.8893	17208.35	3411.114	3.41E+12	0.027778	108.889	60.33338
3377.78	803.334	458.6115	1328.334	22319.46	3366.669	3.37E+12	0.027778	132.5557	1175.834
3825.003	383.0559	433.6115	1798.613	24052.8	3850.003	3.85E+12	0.027778	219.528	1034.445
4433.337	0.027778	326.1114	2281.668	30277.8	4636.115	4.64E+12	0.027778	400.8337	736.945
6172.227	0.027778	294.7225	3666.67	36555.58	5516.671	5.52E+12	0.5	889.7229	1648.335
9786.119	0.027778	1944.168	5850.005	44027.81	6169.449	6.17E+12	2.166668	1421.946	2510.002
15261.12	0.027778	7647.228	9700.008	57055.6	6255.561	6.26E+12	41.36114	1675.001	3394.447

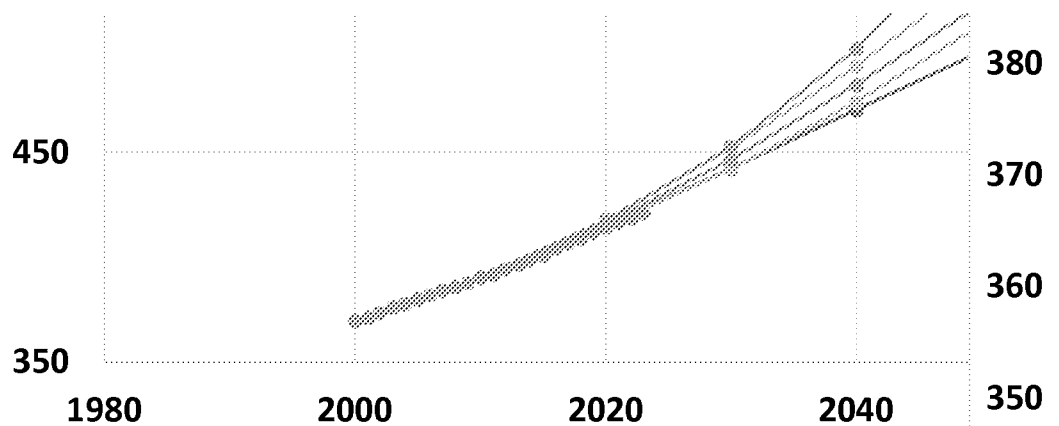
20830.57	0.027778	18188.9	14755.57	63583.38	5897.227	5.9E+12	260.0558	1893.335	4313.892
22838.91	0.027778	33194.47	20319.46	63861.16	5694.449	5.69E+12	932.5007	2822.224	5802.782
21111.13	0.027778	49305.6	23238.91	71611.17	5958.338	5.96E+12	1752.224	4197.226	7663.895
2811.113	1126.112	1.722224	106.9445	15644.46	3627.781	3.63E+12	0	96.36119	0
2830.558	1113.334	65.72227	483.8893	17208.35	3411.114	3.41E+12	0.027778	108.889	60.33338
3369.447	803.334	458.6115	1253.89	20675.02	3322.225	3.32E+12	0.027778	134.7779	1175.001
3416.669	383.0559	433.6115	1448.057	25716.69	3863.892	3.86E+12	0.027778	258.9447	995.2786
2983.336	0.027778	313.3336	1398.612	39472.25	4875.004	4.88E+12	0.027778	491.9448	651.3894
2442.78	0.027778	43.50003	2367.502	49111.15	5833.338	5.83E+12	0.083333	929.4452	1627.779
1726.39	0.027778	103.4445	4191.67	58444.49	6263.894	6.26E+12	2.000002	1322.501	2452.78
1426.668	0.027778	791.1117	6525.005	70472.28	6200.005	6.2E+12	40.30559	1598.335	3155.558
2684.724	0.027778	3691.67	9486.119	76333.39	5975.005	5.98E+12	232.8891	1901.668	3705.559
5347.227	0.027778	11136.12	13575.01	76944.51	6025.005	6.03E+12	815.0007	2174.446	4325.003
9141.674	0.027778	22469.46	17286.12	83333.4	6394.45	6.39E+12	1565.279	2550.835	5058.337

Secondary electricity (oil)	Secondary electricity per capita	Secondary heat per capita	Secondary electricity (% biomass)	Secondary electricity (% biomass CCS)	Secondary electricity (% coal)	Secondary electricity (% coal CCS)	Secondary electricity (% gas)	Secondary electricity (% gas CCS)	Secondary electricity (% geothermal)
41838.84	2781.358		1.215466	0	39.90404	0	20.14455	0	
41630.13	3072.679		1.586964	0	40.42689	0	22.19814	0	
38125.11	3187.006		2.445846	0.007004	21.72262	0.008205	25.0612	0.26517	

SSP Baseline Scenario CO2 Cc



36537.07 5487.
36365.07 6440.
34563.3 7359.
30145.55 8146.
22289.51 8796.
15636.18 9325.
11619.22 9931.
41838.84 2781.
41630.13 3072.
42692.02 3636.
39833.86 4525.



36844.69	5557.244	0.249663	0	34.18498	0	30.55388	0		
36964.42	6529.064	0.115351	0	31.24594	0	27.43118	0		
35621.92	7551.863	0.053612	0	29.23148	0	24.62004	0		
31914.09	8607.167	0.028656	0	27.44096	0	19.83476	0		
24492.02	9603.225	0.008985	0	23.36235	0	16.05231	0		
18211.63	10440.76	0.005963	0	20.3839	0	15.36916	0		
14140.6	11152.39	0.004384	0	17.92447	0	16.86203	0		
45295.59	2779.903	573.6558	0.696056	0	40.44959	0	20.41456	0	0.313456
43729.76	3052.31	535.8663	1.013769	0	41.11528	0	21.63502	0	0.467791
53274.21	3461.436	528.3849	1.750224	0	32.52254	0	26.41151	0	0.336338
43024.48	3828.883	760.2761	0.727062	0.056198	4.06821	1.191574	30.77808	4.374665	0.669986
25624.19	5075.741	845.3352	0.922374	0.514437	1.183329	1.179592	17.71941	12.11729	1.462968
8644.729	6809.857	784.4582	1.80795	1.499655	0.445314	0.442645	10.93667	9.659897	1.589519
3569.17	8845.581	628.5354	1.98262	1.653354	0.214826	0.214826	5.922763	5.034349	1.587434
2706.669	10702.71	586.4342	1.590412	1.424098	0.085078	0.085078	2.566889	2.181842	1.609349
2070.835	12132.13	650.8572	1.504376	1.448884	0.018984	0.018984	0.63451	0.539346	1.465434
1237.501	13543.99	733.0509	1.088414	1.05251	0.003324	0.003324	0.000443	0.000443	1.371433
741.1117	15321.64	815.1507	0.871923	0.84583	0.000201	0.000201	0.000201	0.000201	1.263526
45334.2	2779.946	573.9121	0.696045	0	40.43822	0	20.42808	0	0.313451
43735.31	3052.877	535.8663	1.045379	0	40.98576	0	21.73965	0	0.467705
53039.76	3469.903	558.0195	1.772248	0	32.26753	0.001052	26.56478	0.069417	0.335518
52397.82	3925.039	733.2783	0.973078	0.02998	12.79734	0.398311	37.27932	3.363799	0.161037
48412.82	4556.736	812.1426	0.208816	0.092268	3.601904	1.250121	39.34761	12.06069	0.217835
35384.19	5622.476	927.6626	0.338917	0.218761	1.952142	1.951064	31.37437	23.92842	0.294195
23711.41	6917.234	1037.505	0.670523	0.58751	1.710327	1.709471	23.28475	21.12042	0.356015
10248.34	8527.103	949.4271	1.273497	1.212871	1.321378	1.321378	14.59372	12.68192	0.507745
3358.892	10267.31	976.4925	1.344783	1.316312	0.761545	0.761545	7.479135	6.357236	0.879746
1336.112	12687.84	941.0704	1.206572	1.171558	0.528763	0.528763	3.670346	3.119817	1.105315
615.0005	15510.04	986.3859	0.934498	0.912489	0.343621	0.343621	0.993586	0.844478	1.20416
45334.2	2779.946	573.9121	0.696045	0	40.43822	0	20.42808	0	0.313451
43735.03	3052.877	535.8259	1.045379	0	40.98576	0	21.73965	0	0.467705
53107.26	3463.37	540.903	1.75873	0	32.69194	0.001054	26.1976	0.036882	0.33615
56539.49	3893.368	662.6402	1.118298	0.010363	22.15266	0.034542	37.13526	0.030224	0.163211
56432.82	4407.686	685.2839	0.496303	0.045901	8.675259	0.295487	44.71316	0.818326	0.022233
50787.54	5185.046	682.6065	0.538118	0.148406	1.887211	0.696457	44.49086	3.047583	0.122114
39084.48	6354.734	709.6959	0.686093	0.412215	1.476986	1.273906	34.53566	9.493046	0.204943

29938.08	7451.342	914.2969	0.896408	0.888524	1.300857	1.300857	22.32388	17.7157	0.283035
18543.63	8970.886	1253.849	1.123074	1.117478	1.260002	1.260002	16.75658	15.79084	0.408809
9023.341	11060.15	1363.053	1.168648	1.154806	0.945286	0.945286	11.00011	9.968518	0.595451
4483.059	13384.33	1401.434	1.112786	1.095093	0.85705	0.85705	5.662502	4.813035	0.916331
45334.2	2779.946	573.9121	0.696045	0	40.43822	0	20.42808	0	0.313451
43735.03	3052.917	535.8259	1.045365	0	40.98521	0	21.73936	0	0.467698
53093.93	3457.421	530.7937	1.759645	0	32.82525	0	26.65963	0	0.336729
56576.43	3908.599	648.3848	1.032223	0.003441	23.16479	0.012903	37.64344	0	0.155694
58408.94	4399.783	580.3006	0.340564	0.01437	12.22509	0.056761	46.58538	0	0.016525
56748.66	5125.335	551.1566	0.174961	0.049651	6.824052	0.145406	48.43393	0	0.013595
48098.65	6248.592	614.387	0.228793	0.124107	4.470697	0.278057	44.30813	0.135949	0.006632
36943.09	7385.928	808.7887	0.326106	0.279179	2.192068	0.449788	35.99216	0.900768	0.00517
27800.58	8525.839	1015.174	0.561064	0.558986	0.657692	0.657692	25.48825	4.440719	0.027361
18739.18	10047.94	1254.871	0.759696	0.758501	0.905183	0.905183	12.89871	9.553413	0.168788
12387.51	12111.9	1535.55	0.854664	0.853648	1.168752	1.168752	9.367787	8.762972	0.314088
45334.2	2779.946	573.9121	0.696045	0	40.43822	0	20.42808	0	0.313451
43735.03	3052.877	535.8259	1.045379	0	40.98576	0	21.73965	0	0.467705
53162.82	3457.421	525.3923	1.793424	0	32.90653	0	26.9668	0	0.337784
57157.55	3936.74	575.2251	1.021428	0	25.35037	0	37.84919	0	0.140062
59353.66	4437.907	468.742	0.512156	0	18.49032	0	46.17806	0	0.008548
59348.94	5151.995	406.0739	0.797361	0	15.53972	0	48.96361	0	0.007056
53158.1	6273.396	412.8472	0.696404	0	14.59664	0.008965	46.69255	0	0.003303
47861.43	7518.636	590.8695	0.673126	0	12.53311	0.047662	43.40313	0	0.001563
52468.38	8662.938	837.9764	1.105051	0.000341	8.288568	0.142477	38.46104	0	0.001363
58356.99	9956.237	1211.586	1.262045	0.004221	4.785881	0.323802	34.1156	0	0.001206
61899.22	11504.25	1378.708	1.542183	0.01497	1.28395	0.463805	28.49284	0	0.000802
45334.2	2779.86	573.9121	0.696066	0	40.43946	0	20.42717	0	0.31346
43735.59	3052.877	535.8259	1.045379	0	40.98708	0	21.73832	0	0.467705
52792.26	3459.064	495.8673	1.792572	0	33.71703	0	26.96455	0	0.337624
57207.55	3960.913	507.1421	1.033019	0	27.41533	0	37.16917	0	0.134963
60081.99	4441.194	405.6762	0.590073	0	23.18654	0	44.35729	0	0
60399.49	5157.629	359.3288	0.951559	0	21.75486	0	47.66604	0	0
54948.38	6276.06	359.125	0.734309	0	22.41412	0	45.86674	0	0
50013.1	7597.561	418.9193	0.71098	0	22.39646	0	42.58149	0	0
55763.66	8758.638	589.9999	1.10208	0	23.29606	0	38.24139	0	0
64661.72	10069.07	967.1253	1.311102	0	21.04143	0	34.01114	0	0
71455.89	11668.81	1171.952	1.514373	0	16.50419	0	32.37875	0	0
42995.26	2783.926	568.2285	2.087359	0	38.88077	0	20.51158	0	0.298524
46243.04	2946.698	595.7644	1.859977	0	40.41661	0	19.99838	0	0.278024
56340.13	3261.041	647.1109	1.678197	0	39.92053	0	19.20377	0	0.265794
61105.08	3488.833	674.7537	1.800297	0	33.0187	0	18.52337	0	0.259216
58086.77	3568.272	543.2521	7.063804	1.367435	17.28773	4.156208	16.10556	3.896865	0.26834
55675.96	3944.806	467.8253	15.70704	8.918907	14.99667	9.63006	12.78888	8.188942	0.250912
51254.32	4337.541	436.9298	19.90442	15.92041	14.82666	12.60271	10.72559	9.116758	0.23389
43728.53	4924.507	353.1112	25.17596	20.53821	10.03637	8.530924	8.194734	6.965506	0.211476
36925.67	5459.901	296.1944	26.47527	21.751	7.063829	6.004274	6.36918	5.41384	0.195135
30847.27	6002.84	247.8027	26.6202	21.96623	4.93995	4.198946	4.646615	3.949619	0.181294

26235.8	6529.61	206.5506	25.87955	21.41041	3.46074	2.941621	3.39976	2.88981	0.170905
42995.26	2783.926	568.2285	2.087359	0	38.88077	0	20.51158	0	0.298524
46243.04	2946.698	595.7644	1.859977	0	40.41661	0	19.99838	0	0.278024
56340.13	3261.041	647.1109	1.678197	0	39.92053	0	19.20377	0	0.265794
63034.22	3567.87	673.5335	1.613197	0	36.92238	0	17.24105	0	0.249359
64468.88	3531.7	604.2075	4.182849	0	26.6148	2.049665	16.48865	0	0.261348
62483.47	3621.182	490.5506	12.26769	1.029247	20.86637	9.652352	13.14286	3.548592	0.26386
56033.54	4038.857	414.8743	21.35897	9.818478	17.21295	14.38512	9.563974	6.407874	0.243057
53688.07	4213.208	390.3152	22.68834	18.37713	15.99039	13.59184	8.847122	7.520021	0.239706
49942.43	4520.982	364.9834	24.34278	19.86945	14.60162	12.41138	7.834006	6.658871	0.229059
45456.29	4926.94	334.8401	25.38766	20.85011	12.44142	10.5752	6.683619	5.681093	0.215123
40027.73	5450.881	298.0997	26.25617	21.67921	9.463636	8.044074	5.403823	4.593274	0.199801
42995.26	2783.926	568.2285	2.087359	0	38.88077	0	20.51158	0	0.298524
46243.04	2946.698	595.7644	1.859977	0	40.41661	0	19.99838	0	0.278024
56340.13	3261.041	647.1109	1.678197	0	39.92053	0	19.20377	0	0.265794
63160.05	3578.926	673.3997	1.593537	0	37.29765	0	17.11258	0	0.247495
65919.14	3629.62	638.9162	3.665904	0	32.35244	0.013062	16.07689	0	0.249503
65062.61	3700.082	557.5545	9.920773	0	28.94826	1.371164	14.20127	0	0.251523
62316.36	3789.241	481.3113	15.86175	0	27.98383	2.247802	11.99188	0	0.252413
59921.66	3864.099	399.3551	22.07603	0	22.84492	7.415924	9.931071	0.496537	0.25509
57223.05	4016.51	356.748	24.57677	1.176429	20.86058	13.49151	8.032102	2.608962	0.252003
55341.52	4261.305	338.9972	25.40165	4.732448	21.28436	18.0917	6.780486	3.27007	0.243622
52840.65	4600.414	322.8397	26.90623	8.610958	21.11454	17.94734	5.695377	3.861334	0.23224
42995.26	2783.926	568.2285	2.087359		38.88077		20.51158		0.298524
46344.01	2944.622	597.3916	1.861288		40.76171		20.03593		0.278357
57190.52	3312.546	662.9775	1.64437		43.49415		18.84483		0.263731
64383.13	3694.294	727.5244	1.508624		46.64222		18.33072		0.248597
67908.67	3996.211	766.4564	1.595163		49.67945		17.44903		0.240956
67077.58	4333.171	769.1953	2.030835		52.49602		16.56388		0.22984
64340.94	4531.551	733.654	2.637827		55.37246		15.20623		0.225848
62541.61	4733.012	705.8475	3.409174		58.62282		13.36947		0.222513
60682.22	4942.87	682.1853	4.039637		61.38022		11.69091		0.218638
59865.8	5160.394	658.0579	4.319854		63.88211		10.28177		0.214618
57837.8	5408.951	639.5627	4.70986		66.11424		9.031997		0.210668

46067.12	3157.644		1.006834	0	40.65061	0	23.42063	0	0.312704
49843.43	4003.837		1.267989	0.052744	39.62068	0.227985	24.33558	0.483954	1.538498
47262.85	5200.497		3.268448	2.308036	20.37439	9.647666	19.8147	5.745056	2.7188
44584.21	6295.292		4.470614	4.197032	13.7283	12.39756	15.87799	9.184309	2.592186
39981.31	7351.069		5.654321	5.623829	11.18139	11.08924	12.69454	10.80232	2.328764
30816.31	8279.944		6.576603	6.574768	8.410661	8.404808	11.06671	10.85472	2.088213
22251.64	9109.956		7.254412	7.254341	5.105977	5.105861	9.00403	8.980599	1.90018
14228.09	9828.18		8.001509	8.001507	1.760085	1.760084	6.050449	6.032606	1.744063
8034.094	10531.78		9.37287	9.37287	0.358106	0.358106	3.25817	3.242208	1.628544
3690.22	11456.25		14.51441	14.51441	0.056408	0.056408	0.987427	0.978228	1.189065

46067.12	3157.644		1.006835	0	40.65061	0	23.42063	0	0.312704
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49843.43	4003.837	1.267989	0.052744	39.62068	0.227986	24.33558	0.483954	1.538498
49823.95	4817.781	1.948719	0.482033	30.6839	3.114733	21.84526	2.597297	2.458686
49170.96	5683.402	2.648849	1.471621	19.13712	7.122531	18.92575	4.949768	2.574078
47189.81	6550.439	3.535409	3.033918	11.83977	9.541207	15.35014	7.223306	2.431648
41231.65	7384.546	4.451707	4.355914	9.326567	9.106902	11.49764	8.863253	2.233892
34958.58	8295.921	5.488764	5.480709	7.177804	7.167891	9.148849	8.741092	1.987339
26399.93	9113.482	6.314989	6.314709	5.147211	5.146998	7.629604	7.585801	1.76257
17545.93	9823.1	7.024394	7.024387	2.29436	2.294356	5.488303	5.468959	1.600282
11332.19	10534.38	8.251259	8.251259	0.532057	0.532057	3.182813	3.167756	1.428865

46067.12	3157.644	1.006835	0	40.65061	0	23.42063	0	0.312704
49843.43	4003.837	1.267989	0.052744	39.62068	0.227986	24.33558	0.483954	1.538498
50641.89	4709.373	1.734062	0.221519	33.75131	1.504065	22.85241	1.765053	2.311854
50713.45	5435.012	2.151612	0.578059	25.82325	3.416516	20.42134	3.096103	2.429575
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42125.74	8282.231	4.408569	4.374713	5.738493	5.706966	7.276329	6.661463	1.635354
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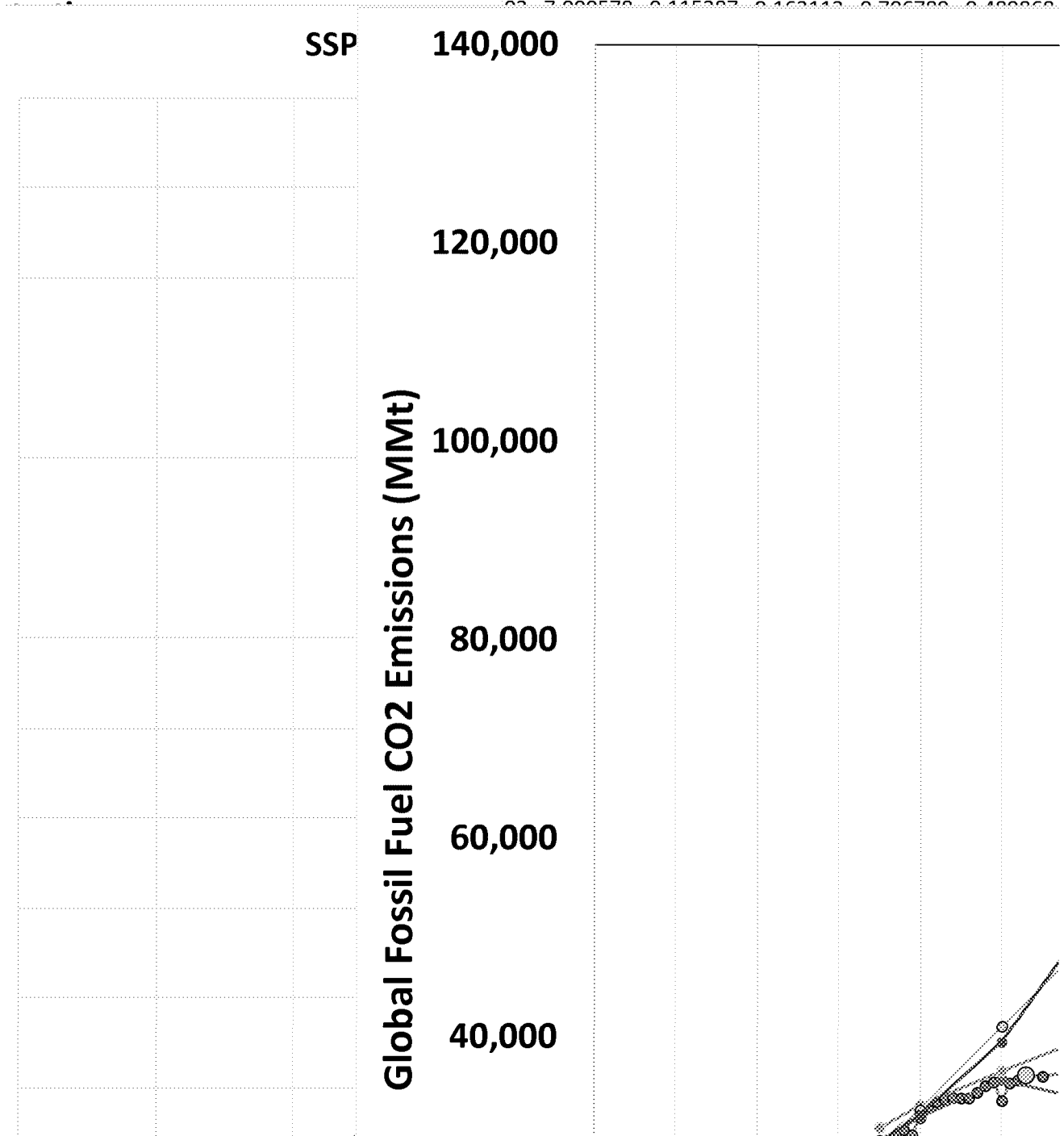
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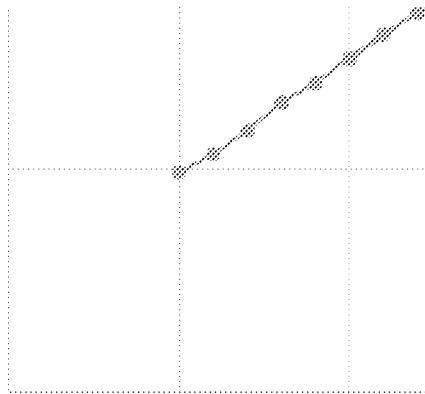
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40500.03	3122.283	494.7946	0.647955	0	39.51478	0	23.93857	0	0.422893
57583.38	3865.793	445.7984	0.630447	0.000285	29.07707	0.000761	39.20076	0.000285	0.386394
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39472.25	2828.169	557.6911	0.523932	0	40.32916	0	20.68549	0	0.331119
40500.03	3122.283	494.7946	0.647955	0	39.51478	0	23.93857	0	0.422893
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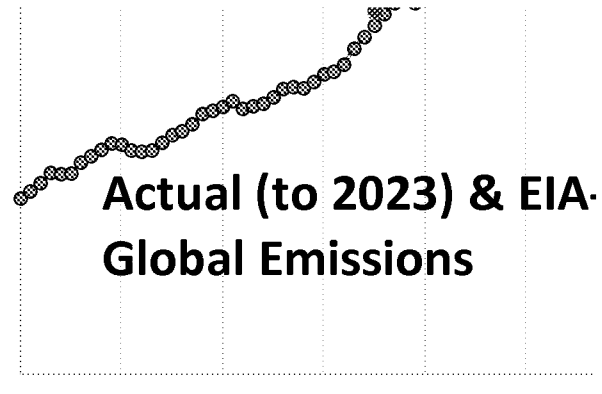
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49500.04	16903.97	867.044	2.713904	0	29.25579	0	20.52139	0	0.27451

Secondary electricity (% of economy)	Secondary electricity (% of economy)	Secondary electricity (% of economy)	Secondary electricity (% of economy)	Secondary electricity (% of economy)	Secondary electricity (% of economy)	Carbon intensity of economy	Carbon intensity of economy	Primary energy intensity	Final energy intensity
Secondary electricity (% of economy)	Secondary electricity (% of economy)	Secondary electricity (% of economy)	Secondary electricity (% of economy)	Secondary electricity (% of economy)	Secondary electricity (% of economy)	Carbon intensity of economy	Carbon intensity of economy	Primary energy intensity	Final energy intensity
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16.17853	18.26484	12.95952	4.563633	0.158573	1.604945	0.518374	0.252548	2.052572	1.49021
18.22686	25.00145	11.81878	2.060006	2.076745	5.277188	0.326167	0.247407	1.318341	0.945668
18.22686	25.00145	11.81878	2.060006	2.076745	5.277188	0.326167	0.247407	1.318341	0.945668





20,000



0

1970 1980 1990 2000 2010 2020

995 2000 2005

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14.49066	29.03973	5.421442	0.198736	1.213075	13.32744	0.266532	0.242321	1.099913	0.8697
12.41143	30.46025	3.657511	0.057626	1.166052	16.87571	0.227439	0.23127	0.983437	0.764017
10.40784	32.36532	4.977683	0.011795	2.002397	19.95178	0.194991	0.22004	0.886164	0.675987
9.11474	34.97285	7.452436	0	3.650818	22.20573	0.164971	0.209359	0.787984	0.59984
8.272548	37.92351	12.71798	0	5.72977	23.91983	0.140623	0.196976	0.71391	0.552205
7.641611	40.07911	16.98906	0	8.175854	24.26044	0.120855	0.183145	0.659888	0.51582
8.834741	41.21017	24.04192	0	9.808864	22.56576	0.102945	0.16847	0.611061	0.484965
16.29226	17.22342	15.06454	6.149355	0.023049	0.594653	0.66809	0.29276	2.282045	1.587266
17.05333	20.05035	12.93673	3.242133	0.328586	2.200729	0.596703	0.289546	2.060826	1.488436
16.11943	23.93543	12.40874	1.181684	1.671239	5.807132	0.417429	0.262126	1.59248	1.2081
14.34683	24.55734	9.295476	0.529666	1.368305	8.70724	0.326607	0.252264	1.294702	1.008225
13.51474	26.41806	5.087159	0.200013	1.038501	11.86482	0.277522	0.247448	1.121538	0.877105
11.47274	26.53556	2.508121	0.057563	0.604416	14.4584	0.244927	0.242112	1.011625	0.773323
9.587523	27.70237	2.642476	0.012262	1.166783	16.94807	0.218891	0.23751	0.921606	0.687514
8.561531	29.69338	3.77411	0	2.231913	18.89993	0.195925	0.234906	0.834058	0.615122
8.009885	29.87213	5.791229	0	2.892917	18.96932	0.186033	0.239752	0.775937	0.568193
7.356839	31.70077	8.817593	0	3.997997	20.34593	0.173938	0.241092	0.72146	0.531625
6.570628	34.50166	11.71359	0	5.658209	22.27282	0.158871	0.236505	0.671744	0.501568
16.02466	16.95758	15.1503	6.412414	0.015679	0.565227	0.628085	0.276043	2.275321	1.696066
16.36955	17.4404	13.8398	6.445106	0.128255	0.617297	0.607927	0.290309	2.094075	1.547959
16.99498	18.76248	13.99999	6.435043	0.233704	1.225949	0.478823	0.281675	1.699913	1.260855
17.6898	23.21142	17.6206	5.825624	0.994689	4.228529	0.37131	0.260101	1.42756	1.075155
21.51475	35.43196	18.03978	6.071171	3.916038	9.695071	0.216502	0.19221	1.126387	0.854092
19.24449	38.71231	12.92035	4.874682	6.862177	12.3215	0.137752	0.126094	1.092455	0.800055
17.07048	41.77232	8.85083	3.920116	8.768587	15.67023	0.092873	0.086476	1.07397	0.759515
15.64078	46.51481	7.096562	2.981513	10.60458	20.03311	0.048749	0.048372	1.007782	0.706322
13.90432	51.58791	6.137003	2.366811	13.43078	24.03638	0.01874	0.019717	0.950457	0.665188
12.12465	56.74189	5.272642	1.778738	16.09665	28.32095	-0.00318	-0.00351	0.904168	0.6371

10.71742	61.46307	4.481484	1.315395	18.81316	31.7456	-0.01593	-0.01846	0.863028	0.615964
16.02466	16.95758	15.1503	6.412414	0.015679	0.565227	0.628085	0.276043	2.275321	1.696066
16.36955	17.4404	13.8398	6.445106	0.128255	0.617297	0.607927	0.290309	2.094075	1.547959
16.99498	18.76248	13.99999	6.435043	0.233704	1.225949	0.478823	0.281675	1.699913	1.260855
17.28951	21.2799	17.19826	5.745127	0.737195	2.967342	0.388499	0.264259	1.470145	1.101031
20.21763	28.57126	17.85572	6.28672	2.246611	5.811858	0.28198	0.228056	1.236454	0.938529
20.38665	33.67071	15.03988	5.012573	4.536392	8.452	0.215431	0.186959	1.152288	0.866914
18.40821	36.93505	11.4404	3.488653	6.546086	11.71019	0.139052	0.125865	1.104774	0.801445
17.57558	40.21683	9.037487	3.219842	7.924414	14.45163	0.099077	0.093631	1.058161	0.760096
16.15492	43.00208	7.316683	2.902822	9.205878	17.38963	0.073999	0.073098	1.012334	0.718791
14.56979	46.8613	6.073285	2.552663	11.08578	20.97087	0.049013	0.050681	0.9671	0.681285
12.8384	51.38704	5.339215	2.150158	13.52769	24.80431	0.025533	0.027874	0.91603	0.644288
16.02466	16.95758	15.1503	6.412414	0.015679	0.565227	0.628085	0.276043	2.275321	1.696066
16.36955	17.4404	13.8398	6.445106	0.128255	0.617297	0.607927	0.290309	2.094075	1.547959
16.99498	18.76248	13.99999	6.435043	0.233704	1.225949	0.478823	0.281675	1.699913	1.260855
17.23555	21.1291	17.14294	5.724188	0.72097	2.889168	0.390129	0.264677	1.473978	1.10307
18.48908	25.46449	16.43345	6.006832	1.842997	4.851249	0.313462	0.241397	1.298538	0.976446
18.83048	28.96696	12.67072	5.292019	3.408609	6.44785	0.273394	0.225203	1.213988	0.911521
17.81583	30.72627	9.132145	4.304127	4.495187	8.135872	0.25638	0.218391	1.173953	0.875251
17.81611	33.93796	7.52753	3.68255	5.636692	10.20453	0.213279	0.191764	1.112195	0.825669
17.1193	37.16067	6.296738	3.073196	7.016066	12.74983	0.169663	0.159108	1.066338	0.780301
15.82104	38.97498	4.880448	2.678071	8.035127	14.85429	0.140415	0.134606	1.04316	0.74905
14.2116	40.19165	3.810809	2.281395	8.861905	16.86758	0.119476	0.11777	1.01449	0.717874
16.02466	16.95758	15.1503	6.412414	0.015679	0.565227	0.628085	0.276043	2.275321	1.696066
16.21874	17.29103	13.60109	6.448826	0.127523	0.619378	0.610386	0.290814	2.098887	1.550577
15.93769	17.05754	12.61464	6.344576	0.16667	0.648053	0.497729	0.286438	1.737652	1.278392
14.66147	15.86957	11.55255	6.096316	0.230934	0.691479	0.421779	0.27317	1.544021	1.119845
14.47781	15.82053	9.534411	5.921341	0.318897	0.749225	0.387362	0.264984	1.461833	1.04263
15.10057	16.54058	7.034269	5.334418	0.414163	0.765812	0.368557	0.259696	1.419185	0.990781
15.18513	16.86061	5.243946	4.678979	0.495114	0.926637	0.357538	0.258235	1.384546	0.948524
14.38194	16.31092	3.989081	4.29854	0.580646	1.099948	0.34533	0.256008	1.348901	0.906845
13.63262	15.94141	3.020356	3.927468	0.711902	1.354677	0.333304	0.253848	1.31301	0.868192
12.77657	15.47109	2.311242	3.733936	0.845073	1.613402	0.324336	0.252724	1.283358	0.835754
11.78802	14.92147	1.85178	3.370691	0.99458	1.908873	0.315302	0.252439	1.249023	0.800633

15.80697	17.84273	12.6582	4.421001	0.153727	1.569328	0.534469	0.253219	2.110704	1.634421
11.84433	20.20278	13.19054	1.382433	1.597702	5.222252	0.401137	0.230785	1.73814	1.318348
8.837917	27.30275	28.08626	1.153441	3.755404	11.99063	0.168345	0.129742	1.29754	0.979863
7.354151	30.71905	34.47532	0.728726	6.396509	14.3762	0.089493	0.082131	1.089629	0.816098
6.549924	32.96311	36.98235	0.524294	9.396815	14.68761	0.054249	0.05678	0.955422	0.703583
6.117089	33.87575	39.65232	0.41796	12.66715	13.0033	0.026504	0.030818	0.860013	0.621382
5.904022	36.31875	41.91606	0.400777	15.73404	12.78051	-0.00044	-0.00057	0.772201	0.557407
5.845282	39.77649	43.90318	0.508285	18.72478	13.46236	-0.03457	-0.04906	0.704561	0.50898
5.844488	45.62255	40.68446	0.703838	23.04646	15.10306	-0.05782	-0.08701	0.6645	0.472281
5.598358	47.78113	36.24072	0.419906	25.90907	15.08463	-0.07822	-0.11974	0.653289	0.449928

15.80697	17.84273	12.6582	4.421	0.153726	1.569329	0.534469	0.253219	2.110704	1.634421
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11.84432	20.20278	13.19054	1.382435	1.597703	5.222252	0.4012	0.230786	1.738411	1.318554
9.539985	24.34445	19.98966	1.188018	3.215254	9.130521	0.24793	0.17961	1.380383	1.028684
8.145917	29.23466	29.2187	0.834921	5.883756	12.63091	0.154034	0.135595	1.135985	0.860344
7.35049	33.11732	35.55286	0.604497	9.169982	14.1652	0.091002	0.094028	0.967813	0.742431
6.858954	35.88578	38.33486	0.503449	12.79574	13.99719	0.058812	0.068247	0.861763	0.654724
6.483938	37.42747	40.37349	0.383622	16.00822	12.94798	0.036364	0.046796	0.777066	0.585123
6.303682	39.07584	41.47742	0.354929	18.43739	12.5722	0.009023	0.012667	0.712335	0.530669
6.266134	43.47341	41.31107	0.408466	21.86819	13.7388	-0.02159	-0.03288	0.656581	0.486721
6.088275	48.86499	38.61675	0.552127	26.29503	15.05282	-0.04534	-0.07308	0.620321	0.452431
15.80697	17.84273	12.6582	4.421	0.153726	1.569329	0.534469	0.253219	2.110704	1.634421
11.84432	20.20278	13.19054	1.382435	1.597703	5.222252	0.4012	0.230786	1.738411	1.318554
9.759592	23.14743	17.2999	1.214886	2.979619	8.096366	0.279292	0.196913	1.418352	1.053609
8.5182	27.04139	23.70065	0.861763	5.314578	10.77904	0.200445	0.168802	1.187462	0.886726
7.857063	31.41135	30.98084	0.635937	8.526609	12.6422	0.132509	0.131605	1.006873	0.768649
7.433364	36.30901	36.36458	0.601452	12.58005	13.9869	0.085367	0.097317	0.877203	0.679941
7.041799	39.10198	39.20441	0.445063	16.2506	13.70554	0.05577	0.071491	0.780095	0.607302
7.198403	40.07471	40.61334	0.279512	18.62333	12.40307	0.035564	0.049465	0.718973	0.565768
7.431918	41.52757	40.75131	0.29773	20.70265	11.75765	0.029613	0.044349	0.667731	0.529035
7.303475	45.23147	39.1359	0.270609	24.0103	12.44168	0.021852	0.035212	0.620595	0.492549
15.80697	17.84273	12.6582	4.421	0.153726	1.569329	0.534469	0.253219	2.110704	1.634421
11.84432	20.20278	13.19054	1.382435	1.597703	5.222252	0.4012	0.230786	1.738411	1.318554
9.801178	21.56375	14.8097	1.273894	2.599696	7.069301	0.326509	0.219831	1.485276	1.095257
8.821727	24.00515	17.86649	0.913127	4.417638	8.612342	0.268577	0.211128	1.272107	0.934471
8.495586	26.05471	20.6892	0.675193	6.77248	8.74582	0.223878	0.200754	1.115188	0.823003
8.460043	29.55622	23.27916	0.716063	9.818264	9.315739	0.189219	0.189511	0.998461	0.741052
8.478483	32.69375	25.89845	0.60189	12.84106	9.495384	0.158243	0.177578	0.891119	0.672592
8.554225	37.96659	29.64627	0.582044	16.37962	11.14052	0.119741	0.151533	0.790195	0.616311
8.585799	43.6945	32.80231	0.551481	20.42809	12.8645	0.086469	0.122549	0.705585	0.56729
8.31915	49.80178	34.67413	0.436037	25.49229	14.32518	0.05842	0.091864	0.635942	0.524164
15.74575	16.6407	14.85831	5.973432	0.024376	0.558151	0.562247	0.248977	2.258227	1.758602
15.80697	17.84273	12.6582	4.421	0.153726	1.569329	0.534469	0.253219	2.110704	1.634421
11.74132	19.37555	12.33374	1.584861	1.478757	4.683824	0.4171	0.235025	1.774704	1.338654
9.716438	20.90363	14.09384	1.300745	2.494723	6.677669	0.347385	0.230126	1.509546	1.101528
8.766817	23.12129	16.77656	0.962565	4.198503	8.089081	0.295174	0.226768	1.301656	0.942107
8.463815	25.00174	19.11937	0.72449	6.354316	8.236976	0.254044	0.221342	1.147741	0.83217
8.492743	27.9789	21.26152	0.782858	9.145658	8.481339	0.226344	0.218357	1.036578	0.752965
8.601616	30.54107	23.29764	0.683544	11.8213	8.371593	0.198369	0.212244	0.934631	0.688072
8.838581	34.69862	26.01733	0.695965	14.66959	9.462769	0.166481	0.197799	0.841669	0.636466
9.126039	38.54444	27.24572	0.687425	17.39128	10.37899	0.143887	0.186904	0.769846	0.593411
9.182991	42.12698	27.19789	0.620882	20.28914	11.12531	0.127196	0.178429	0.712868	0.557598
16.14072	17.06175	15.28008	6.121093	0.009361	0.581308	0.622332	0.273371	2.276515	1.620412
14.60834	17.58937	13.15008	5.17228	0.30533	2.248032	0.538257	0.260458	2.066583	1.465148
10.23787	16.74596	11.56993	2.751665	1.570885	4.549952	0.389598	0.230591	1.689566	1.228875
11.08605	23.63409	17.51044	1.152047	2.80284	8.947368	0.232002	0.213089	1.08876	0.842377
17.13217	45.5798	25.59227	6.23E-05	11.34663	16.34663	0.089781	0.128867	0.696698	0.538547

15.67396	61.2326	23.02584	7.95E-05	25.87674	19.18887	0.003706	0.006323	0.586092	0.420115
12.38259	70.189	19.20676	2.86E-05	37.68614	19.76804	-0.02914	-0.0602	0.484063	0.341076
10.26673	75.12072	16.55323	2.3E-05	44.88388	19.72178	-0.02902	-0.06779	0.428026	0.30501
8.977673	79.25969	13.87779	1.96E-05	50.23502	19.81982	-0.02612	-0.0675	0.386947	0.278466
8.048739	82.54677	11.52737	1.72E-05	54.23031	20.06178	-0.02387	-0.06826	0.349681	0.256173
7.450336	84.88972	9.806038	1.56E-05	57.92273	19.34929	-0.0222	-0.07025	0.31594	0.234033
16.14072	17.06175	15.28008	6.121093	0.009361	0.581308	0.621449	0.272983	2.276515	1.620412
14.60834	17.58937	13.15008	5.17228	0.30533	2.248032	0.537739	0.260207	2.066583	1.465148
10.23787	16.74596	11.56993	2.751665	1.570885	4.549952	0.388236	0.229785	1.689566	1.228875
8.445596	16.43227	12.72391	1.020725	1.373057	6.016284	0.26208	0.219667	1.193079	0.908892
10.52077	23.68051	17.10942	5.85E-05	2.967232	9.549444	0.149391	0.185841	0.803864	0.631522
13.1634	37.47277	20.81917	4.36E-05	9.986928	13.79956	0.071062	0.110243	0.644593	0.491405
12.62798	51.41832	20.57385	3.26E-05	22.12586	16.25041	0.016411	0.030478	0.538439	0.385112
10.95226	63.17928	18.51193	2.54E-05	34.33215	17.56729	-0.00691	-0.01535	0.450571	0.320446
9.335716	73.57578	16.00799	2.1E-05	45.28064	18.72399	-0.01614	-0.04115	0.392159	0.282597
8.048955	80.22155	12.6139	1.79E-05	52.20654	19.76059	-0.01979	-0.0557	0.35522	0.257018
7.33784	83.58281	10.15291	1.61E-05	56.75197	19.29825	-0.01946	-0.05987	0.325005	0.235621
16.14072	17.06175	15.28008	6.121093	0.009361	0.581308	0.621449	0.272983	2.276515	1.620412
14.60834	17.58937	13.15008	5.17228	0.30533	2.248032	0.537739	0.260207	2.066583	1.465148
10.23787	16.74596	11.56993	2.751665	1.570885	4.549952	0.388124	0.229718	1.689566	1.228875
7.639576	14.38163	10.97527	0.974558	1.132862	5.065724	0.269866	0.221877	1.21629	0.917274
8.077994	16.48468	12.39554	5.57E-05	1.208914	6.618384	0.170142	0.200358	0.849188	0.65937
10.12048	24.24269	14.71601	4.3E-05	3.783993	9.845095	0.105292	0.155041	0.679126	0.526012
11.33628	36.79021	16.47059	3.4E-05	12.23053	12.82897	0.061509	0.108627	0.566244	0.42087
10.9792	51.62275	17.24272	2.77E-05	25.01248	15.29542	0.026557	0.056655	0.46875	0.340754
9.780543	65.63348	16.48416	2.26E-05	38.23529	17.32579	0.003853	0.009587	0.401888	0.293472
8.499425	76.0253	14.18743	1.92E-05	48.10272	19.20276	-0.01008	-0.02835	0.355461	0.261743
7.630638	81.10638	11.36	1.7E-05	54.24681	19.01277	-0.01378	-0.04333	0.31812	0.236
16.14072	17.06175	15.28008	6.121093	0.009361	0.581308	0.621449	0.272983	2.276515	1.620412
14.60834	17.58937	13.15008	5.17228	0.30533	2.248032	0.537739	0.260207	2.066583	1.465148
10.23787	16.74596	11.56993	2.751665	1.570885	4.549952	0.388052	0.229676	1.689566	1.228875
7.514045	14.1573	10.74438	0.968399	1.10323	5.011938	0.272493	0.222385	1.225323	0.922277
7.622996	15.24046	11.83527	5.53E-05	0.852405	6.20785	0.179417	0.205648	0.872444	0.674944
9.336513	20.49003	14.29748	4.34E-05	1.911969	8.755421	0.120941	0.169029	0.715508	0.549649
10.84567	29.98238	16.70895	3.52E-05	7.417195	11.30374	0.079664	0.130553	0.610207	0.451493
10.71892	42.04478	17.39835	2.95E-05	17.2363	13.72422	0.050004	0.097715	0.511734	0.371077
10.05202	55.26381	16.58905	2.48E-05	28.98192	15.92767	0.03272	0.074553	0.43888	0.322588
9.282937	66.60907	14.73002	2.16E-05	38.89849	18.16199	0.019887	0.052819	0.376506	0.282508
8.759226	73.48893	12.5394	1.99E-05	45.64133	18.84101	0.015673	0.046802	0.334871	0.254968
16.14072	17.06175	15.28008	6.121093	0.009361	0.581308	0.621449	0.272983	2.276515	1.620412
14.60834	17.58937	13.15008	5.17228	0.30533	2.248032	0.537739	0.260207	2.066583	1.465148
10.23787	16.74596	11.56993	2.751665	1.570885	4.549952	0.388227	0.229779	1.689566	1.228875
6.965986	12.91156	9.367347	0.938095	1.061905	4.404762	0.289214	0.228183	1.267467	0.944176
5.930962	11.32845	8.34728	5.23E-05	0.614017	4.296025	0.211044	0.223489	0.944316	0.714932
6.804384	13.2715	9.367622	4.22E-05	0.447302	5.564924	0.161099	0.204116	0.789256	0.59048
8.942203	19.56379	12.80625	3.64E-05	2.544166	7.655398	0.12482	0.181353	0.688268	0.494965
10.06378	30.36033	17.51913	3.19E-05	8.778699	11.1352	0.092737	0.159901	0.579966	0.415945

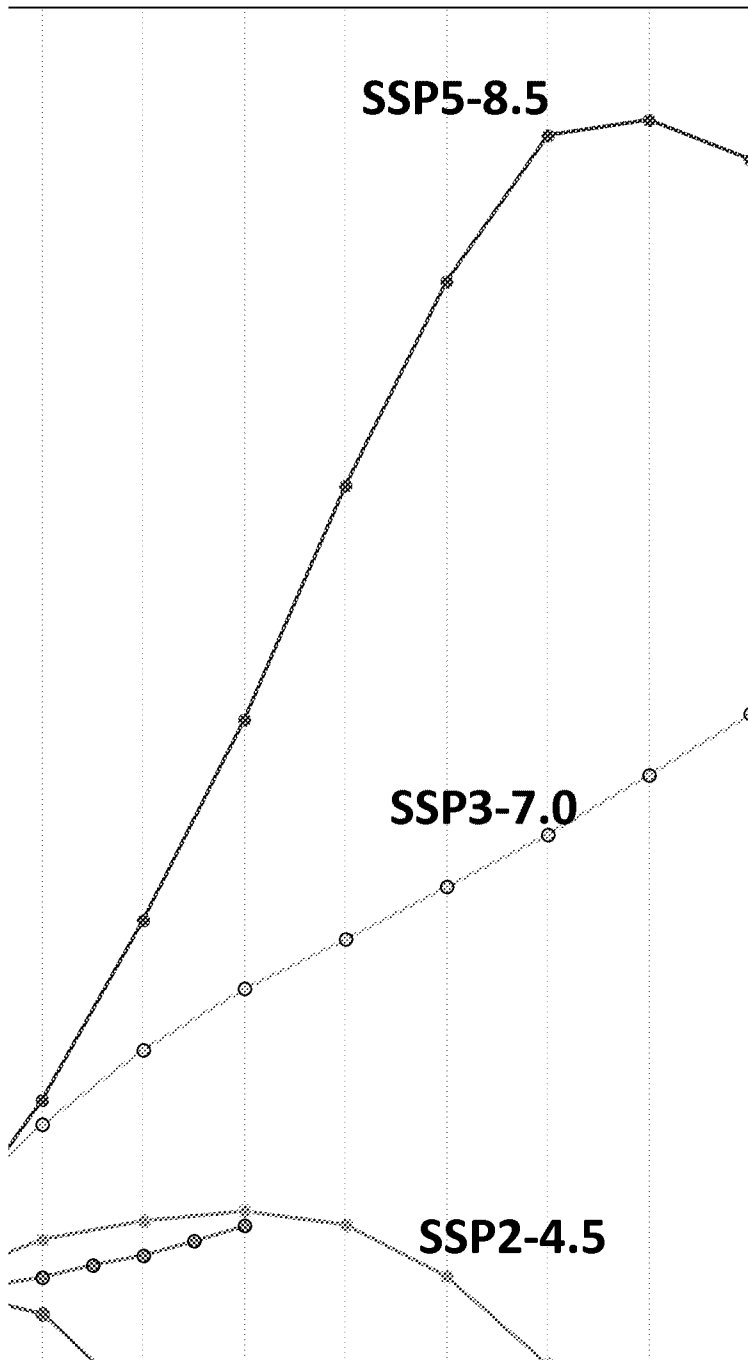
9.986252	42.94748	20.61864	2.75E-05	18.00385	14.60544	0.069319	0.14259	0.48614	0.358433
9.620763	55.58189	19.48803	2.37E-05	28.32425	17.33823	0.050766	0.124274	0.408497	0.308447
9.518229	66.44965	16.49306	2.17E-05	38.51997	18.15538	0.040166	0.112073	0.358388	0.274238
16.14072	17.06175	15.28008	6.121093	0.009361	0.581308	0.622326	0.273368	2.276515	1.620412
14.60834	17.58937	13.15008	5.17228	0.30533	2.248032	0.538273	0.260466	2.066583	1.465148
9.869281	15.96639	11.32586	2.70028	1.54155	4.214753	0.437786	0.256218	1.708648	1.228057
6.412677	11.3149	8.293999	0.929872	1.052596	3.515172	0.342138	0.258631	1.32288	0.963846
4.422156	7.824351	5.359281	4.99E-05	0.562874	2.512475	0.268492	0.257818	1.041401	0.760206
3.912821	7.688363	3.469034	3.94E-05	0.061775	3.36213	0.231523	0.259805	0.891144	0.638044
4.702721	10.2385	2.087672	3.36E-05	0.125092	5.068861	0.211795	0.263501	0.803773	0.546148
6.1875	14.35417	1.528571	2.98E-05	0.847619	6.991071	0.193958	0.268401	0.722645	0.470453
7.540678	20.50147	2.578021	2.67E-05	3.544945	9.109096	0.174857	0.268547	0.651124	0.415579
7.899687	29.63588	4.64191	2.41E-05	9.667229	11.78442	0.147793	0.261522	0.565127	0.359226
8.019162	40.19608	7.332888	2.23E-05	18.02362	13.86586	0.122306	0.248877	0.491433	0.31442

Final
energy as

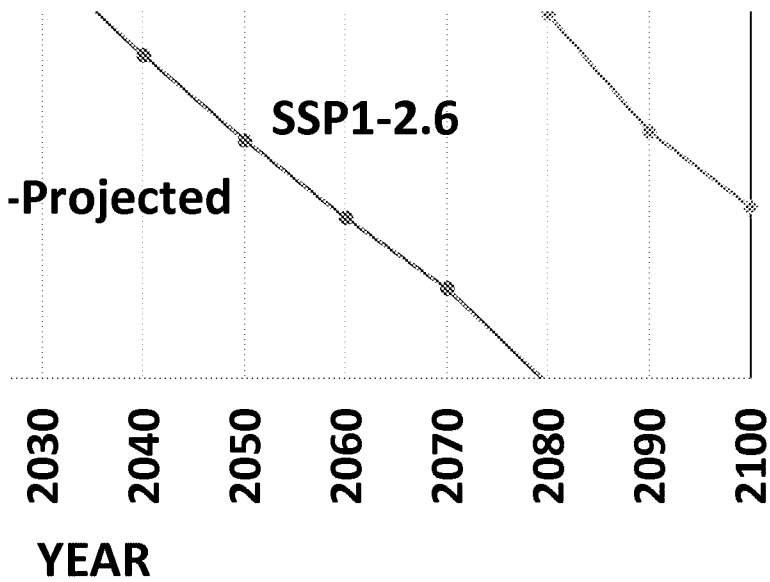
a share of final_ener

primary gy_biomass final_ener primary_e final_ener
energy s gy_coal gy_solar n nergy_inte gy_intensi
ty

74.23929	37.99325	31.6265	0.016459	Sustainabi	0.007996	0.005936	SSP1 - 1.9	2005
72.60206	43.75728	39.65266	0.121414	Sustainabi	0.007389	0.005365	SSP1 - 1.9	2010
71.73168	28.30574	35.73998	1.805154	Sustainabi	0.004746	0.003404	SSP1 - 1.9	2020
68.28882	24.8782	36.5562	2.318601	Sustainabi	0.003544	0.001764	SSP1 - 1.9	2030



01295	SSP1 - 1.9	2040
01101	SSP1 - 1.9	2050
00966	SSP1 - 1.9	2060
00086	SSP1 - 1.9	2070
00772	SSP1 - 1.9	2080
00694	SSP1 - 1.9	2090
00629	SSP1 - 1.9	2100
05936	SSP1 - 2.6	2005
05365	SSP1 - 2.6	2010
03783	SSP1 - 2.6	2020
02558	SSP1 - 2.6	2030
00186	SSP1 - 2.6	2040
00147	SSP1 - 2.6	2050
01244	SSP1 - 2.6	2060
00105	SSP1 - 2.6	2070
00895	SSP1 - 2.6	2080
00079	SSP1 - 2.6	2090
00737	SSP1 - 2.6	2100
05936	SSP1 - 3.4	2005
05365	SSP1 - 3.4	2010
03881	SSP1 - 3.4	2020
02765	SSP1 - 3.4	2030
02115	SSP1 - 3.4	2040
01733	SSP1 - 3.4	2050
01467	SSP1 - 3.4	2060
01218	SSP1 - 3.4	2070
0.001	SSP1 - 3.4	2080
00085	SSP1 - 3.4	2090
00768	SSP1 - 3.4	2100
05936	SSP1 - 4.5	2005
05365	SSP1 - 4.5	2010
00388	SSP1 - 4.5	2020
02803	SSP1 - 4.5	2030



02213	SSP1 - 4.5	2040
01857	SSP1 - 4.5	2050
00159	SSP1 - 4.5	2060
01344	SSP1 - 4.5	2070
00113	SSP1 - 4.5	2080
00952	SSP1 - 4.5	2090
00829	SSP1 - 4.5	2100
05936	SSP1 - Base	2005
05365	SSP1 - Base	2010
03882	SSP1 - Base	2020
02811	SSP1 - Base	2030
02241	SSP1 - Base	2040
00188	SSP1 - Base	2050
01631	SSP1 - Base	2060
01419	SSP1 - Base	2070
01233	SSP1 - Base	2080

75.37708	53.76987	9.049482	117.3867	Sustainabi	0.00142	0.00107	SSP1 - Base	2090
75.40109	47.2859	6.338364	118.0513	Sustainabi	0.001239	0.000934	SSP1 - Base	2100
69.56632	38.956	27.038	0.293	Middle of	0.008215	0.005715	SSP2 - 1.9	2005
72.34056	44.775	35.721	2.23	Middle of	0.007407	0.005359	SSP2 - 1.9	2010
76.3517	48.623	38.558	8.824	Middle of	0.005696	0.004349	SSP2 - 1.9	2020
83.24243	57.896	13.387	18.646	Middle of	0.003607	0.003002	SSP2 - 1.9	2030
82.00403	52.67	0.398	27.833	Middle of	0.002831	0.002322	SSP2 - 1.9	2040
79.67295	47.235	0.04	32.687	Middle of	0.002463	0.001962	SSP2 - 1.9	2050
78.17842	33.067	0.001	36.245	Middle of	0.002251	0.00176	SSP2 - 1.9	2060
77.73421	14.144	0	39.088	Middle of	0.002029	0.001577	SSP2 - 1.9	2070
77.77272	7.201	0	40.737	Middle of	0.001841	0.001432	SSP2 - 1.9	2080
77.40471	4.467	0	41.086	Middle of	0.001698	0.001315	SSP2 - 1.9	2090
77.05598	4.489	0	41.327	Middle of	0.00159	0.001225	SSP2 - 1.9	2100
69.55144	38.956	27.038	0.293	Middle of	0.008216	0.005714	SSP2 - 2.6	2005
72.22695	44.864	35.721	2.231	Middle of	0.00742	0.005359	SSP2 - 2.6	2010
76.39975	49.601	37.912	9.05	Middle of	0.005679	0.004339	SSP2 - 2.6	2020
81.21782	57.611	31.198	19.841	Middle of	0.004127	0.003352	SSP2 - 2.6	2030
81.55205	54.389	16.345	30.819	Middle of	0.003353	0.002734	SSP2 - 2.6	2040
79.58487	50.914	6.86	37.236	Middle of	0.002888	0.002299	SSP2 - 2.6	2050
77.84664	43.155	4.292	41.53	Middle of	0.002602	0.002026	SSP2 - 2.6	2060
75.94345	28.18	1.089	44.537	Middle of	0.002366	0.001797	SSP2 - 2.6	2070
76.38073	24.909	0	46.738	Middle of	0.002133	0.001629	SSP2 - 2.6	2080
76.86084	20.003	0	47.698	Middle of	0.001933	0.001486	SSP2 - 2.6	2090
78.02526	11.127	0	48.498	Middle of	0.001769	0.00138	SSP2 - 2.6	2100
69.55144	38.956	27.038	0.293	Middle of	0.008216	0.005714	SSP2 - 3.4	2005
72.22507	44.864	35.721	2.231	Middle of	0.00742	0.005359	SSP2 - 3.4	2010
76.3303	48.464	37.969	8.889	Middle of	0.00568	0.004336	SSP2 - 3.4	2020
79.23507	54.286	41.38	19.4	Middle of	0.004408	0.003492	SSP2 - 3.4	2030
81.31629	56.41	38.551	31.222	Middle of	0.003637	0.002957	SSP2 - 3.4	2040
80.71405	57.171	33.67	39.01	Middle of	0.003149	0.002542	SSP2 - 3.4	2050
79.20049	52.13	27.042	44.061	Middle of	0.002767	0.002192	SSP2 - 3.4	2060

78.31587	33.64	20.03	47.211	Middle of	0.002504	0.001961	SSP2 - 3.4	2070
76.94987	19.183	7.843	49.817	Middle of	0.002308	0.001776	SSP2 - 3.4	2080
76.52445	17.861	2.288	51.275	Middle of	0.002109	0.001614	SSP2 - 3.4	2090
76.79779	20.99	0.116	52.505	Middle of	0.00195	0.001498	SSP2 - 3.4	2100
69.55144	38.956	27.038	0.293	Middle of	0.008216	0.005714	SSP2 - 4.5	2005
72.22507	44.864	35.721	2.231	Middle of	0.007419	0.005359	SSP2 - 4.5	2010
76.24707	48.531	39.484	8.81	Middle of	0.005694	0.004341	SSP2 - 4.5	2020
79.04371	53.793	53.068	19.039	Middle of	0.004507	0.003562	SSP2 - 4.5	2030
80.70134	56.237	59.416	30.785	Middle of	0.003806	0.003072	SSP2 - 4.5	2040
80.07156	56.577	57.55	40.035	Middle of	0.003342	0.002676	SSP2 - 4.5	2050
78.91855	55.143	56.143	45.579	Middle of	0.00295	0.002328	SSP2 - 4.5	2060
79.16838	50.258	56.04	48.923	Middle of	0.002606	0.002063	SSP2 - 4.5	2070
79.4836	35.842	51.498	51.44	Middle of	0.002364	0.001879	SSP2 - 4.5	2080
79.40343	22.835	36.647	52.965	Middle of	0.002172	0.001724	SSP2 - 4.5	2090
77.7537	16.314	16.616	54.306	Middle of	0.002055	0.001598	SSP2 - 4.5	2100
69.55159	38.956	27.038	0.293	Middle of	0.008216	0.005714	SSP2 - 6.0	2005
72.22695	44.864	35.721	2.231	Middle of	0.007419	0.005358	SSP2 - 6.0	2010
76.16588	48.396	40.058	8.81	Middle of	0.005701	0.004342	SSP2 - 6.0	2020
78.34123	53.308	58.527	19.092	Middle of	0.004601	0.003604	SSP2 - 6.0	2030
79.06991	52.905	72.354	30.211	Middle of	0.00396	0.003131	SSP2 - 6.0	2040
77.68846	48.811	78.316	38.829	Middle of	0.00354	0.00275	SSP2 - 6.0	2050
76.28232	49.767	86.74	46.579	Middle of	0.00319	0.002434	SSP2 - 6.0	2060
76.12337	45.842	91.896	50.762	Middle of	0.002837	0.002159	SSP2 - 6.0	2070
77.34939	35.626	99.397	53.526	Middle of	0.00257	0.001988	SSP2 - 6.0	2080
78.16779	27.374	104.753	55.537	Middle of	0.002376	0.001857	SSP2 - 6.0	2090
79.36445	32.217	103.076	57.178	Middle of	0.0022	0.001746	SSP2 - 6.0	2100
69.55454	38.956	27.038	0.293	Middle of	0.008215	0.005714	SSP2 - Base	2005
72.22522	44.858	35.727	2.231	Middle of	0.007419	0.005358	SSP2 - Base	2010
75.86277	48.381	42.691	8.809	Middle of	0.005733	0.004349	SSP2 - Base	2020
77.87315	52.933	63.242	18.902	Middle of	0.004661	0.00363	SSP2 - Base	2030
78.20559	52.613	76.553	29.662	Middle of	0.004038	0.003158	SSP2 - Base	2040
76.44368	47.924	85.508	38.879	Middle of	0.003642	0.002784	SSP2 - Base	2050
74.59954	49.317	96.465	46.568	Middle of	0.003318	0.002475	SSP2 - Base	2060
73.75047	49.562	109.512	51.295	Middle of	0.003003	0.002214	SSP2 - Base	2070
73.22668	37.785	119.793	54.153	Middle of	0.002793	0.002045	SSP2 - Base	2080
73.68731	24.012	123.869	56.363	Middle of	0.002597	0.001914	SSP2 - Base	2090
74.66659	23.503	130.726	58.542	Middle of	0.002418	0.001806	SSP2 - Base	2100
74.54186	42.4489	29.001		Regional R	0.008191	0.006106	SSP3 - 3.4	2005
73.92089	44.9529	30.2587		Regional R	0.007539	0.005573	SSP3 - 3.4	2010
74.17174	51.7927	35.6223		Regional R	0.00612	0.004539	SSP3 - 3.4	2020
75.31418	59.121	40.0743		Regional R	0.005139	0.003871	SSP3 - 3.4	2030
75.82584	64.4824	12.0058		Regional R	0.004055	0.003075	SSP3 - 3.4	2040
73.2346	69.7055	9.7741		Regional R	0.003933	0.00288	SSP3 - 3.4	2050
70.72037	74.9753	8.7745		Regional R	0.003866	0.002734	SSP3 - 3.4	2060
70.08677	80.5794	6.4582		Regional R	0.003628	0.002543	SSP3 - 3.4	2070
69.98614	86.9292	4.804		Regional R	0.003422	0.002395	SSP3 - 3.4	2080
70.46255	93.804	3.6727		Regional R	0.003255	0.002294	SSP3 - 3.4	2090

71.37246	101.6462	2.9019	Regional R	0.003107	0.002217	SSP3 - 3.4	2100
74.54186	42.4489	29.001	Regional R	0.008191	0.006106	SSP3 - 4.5	2005
73.92089	44.9529	30.2587	Regional R	0.007539	0.005573	SSP3 - 4.5	2010
74.17174	51.7927	35.6223	Regional R	0.00612	0.004539	SSP3 - 4.5	2020
74.89266	59.0726	41.3861	Regional R	0.005293	0.003964	SSP3 - 4.5	2030
75.90491	64.7857	22.3737	Regional R	0.004451	0.003379	SSP3 - 4.5	2040
75.23415	70.1531	19.1606	Regional R	0.004148	0.003121	SSP3 - 4.5	2050
72.54375	75.354	14.0575	Regional R	0.003977	0.002885	SSP3 - 4.5	2060
71.83179	81.3597	13.2908	Regional R	0.003809	0.002736	SSP3 - 4.5	2070
71.00334	88.1788	12.0531	Regional R	0.003644	0.002588	SSP3 - 4.5	2080
70.44611	95.6327	10.369	Regional R	0.003482	0.002453	SSP3 - 4.5	2090
70.33485	103.8517	8.3042	Regional R	0.003298	0.002319	SSP3 - 4.5	2100
74.54186	42.4489	29.001	Regional R	0.008191	0.006106	SSP3 - 6.0	2005
73.92089	44.9529	30.2587	Regional R	0.007539	0.005573	SSP3 - 6.0	2010
74.17174	51.7927	35.6223	Regional R	0.00612	0.004539	SSP3 - 6.0	2020
74.83623	59.0691	41.5464	Regional R	0.005306	0.003971	SSP3 - 6.0	2030
75.19577	64.9432	30.0196	Regional R	0.004675	0.003515	SSP3 - 6.0	2040
75.08484	70.4399	28.3452	Regional R	0.00437	0.003281	SSP3 - 6.0	2050
74.55587	76.0075	30.7126	Regional R	0.004226	0.003151	SSP3 - 6.0	2060
74.23778	82.0606	28.5246	Regional R	0.004004	0.002972	SSP3 - 6.0	2070
73.17573	89.0395	26.1171	Regional R	0.003839	0.002809	SSP3 - 6.0	2080
71.80588	97.0327	25.4504	Regional R	0.003755	0.002697	SSP3 - 6.0	2090
70.76208	106.2671	25.3365	Regional R	0.003652	0.002584	SSP3 - 6.0	2100
74.54186	42.4489	29.001	Regional R	0.008191	0.006106	SSP3 - Base	2005
73.87617	44.9515	30.4891	Regional R	0.007556	0.005582	SSP3 - Base	2010
73.57008	51.7704	37.0095	Regional R	0.006256	0.004602	SSP3 - Base	2020
72.5278	59.046	42.5777	Regional R	0.005558	0.004031	SSP3 - Base	2030
71.32345	65.1974	45.1695	Regional R	0.005263	0.003753	SSP3 - Base	2040
69.81339	70.9768	46.646	Regional R	0.005109	0.003567	SSP3 - Base	2050
68.50797	76.7886	47.5485	Regional R	0.004984	0.003415	SSP3 - Base	2060
67.22841	83.247	49.0407	Regional R	0.004856	0.003265	SSP3 - Base	2070
66.12225	90.6822	50.4554	Regional R	0.004727	0.003125	SSP3 - Base	2080
65.12244	99.1394	52.5132	Regional R	0.00462	0.003009	SSP3 - Base	2090
64.10075	109.0032	54.8346	Regional R	0.004496	0.002882	SSP3 - Base	2100
			Inequality - A Road Divided			SSP4 - 2.6	2005
77.43486	47.0715	49.97054	Inequality	0.007599	0.005884	SSP4 - 2.6	2010
75.84824	54.16237	57.63439	Inequality	0.006257	0.004746	SSP4 - 2.6	2020
75.517	60.35671	26.15188	Inequality	0.004671	0.003528	SSP4 - 2.6	2030
74.89686	58.67725	17.14337	Inequality	0.003923	0.002938	SSP4 - 2.6	2040
73.6411	55.22856	9.787412	Inequality	0.00344	0.002533	SSP4 - 2.6	2050
72.25267	51.3831	5.373374	Inequality	0.003096	0.002237	SSP4 - 2.6	2060
72.18422	48.54091	2.951482	Inequality	0.00278	0.002007	SSP4 - 2.6	2070
72.24069	46.63671	1.747409	Inequality	0.002536	0.001832	SSP4 - 2.6	2080
71.07323	44.07989	1.038943	Inequality	0.002392	0.0017	SSP4 - 2.6	2090
68.8712	39.21269	0.607058	Inequality	0.002352	0.00162	SSP4 - 2.6	2100
			Inequality - A Road Divided			SSP4 - 3.4	2005
77.43486	47.0715	49.97054	Inequality	0.007599	0.005884	SSP4 - 3.4	2010

75.84824	54.16237	57.63439	Inequality	0.006258	0.004747	SSP4 - 3.4	2020
74.52167	61.19682	39.63659	Inequality	0.004969	0.003703	SSP4 - 3.4	2030
75.73551	62.45115	30.11007	Inequality	0.00409	0.003097	SSP4 - 3.4	2040
76.71224	61.31555	19.63707	Inequality	0.003484	0.002673	SSP4 - 3.4	2050
75.97497	57.28701	11.40229	Inequality	0.003102	0.002357	SSP4 - 3.4	2060
75.29892	51.93248	5.993333	Inequality	0.002797	0.002106	SSP4 - 3.4	2070
74.49711	47.06265	3.217766	Inequality	0.002564	0.00191	SSP4 - 3.4	2080
74.12964	43.27613	1.853986	Inequality	0.002364	0.001752	SSP4 - 3.4	2090
72.93502	39.92146	1.099065	Inequality	0.002233	0.001629	SSP4 - 3.4	2100
			Inequality - A Road Divided			SSP4 - 4.5	2005
77.43486	47.0715	49.97054	Inequality	0.007599	0.005884	SSP4 - 4.5	2010
75.84824	54.16237	57.63439	Inequality	0.006258	0.004747	SSP4 - 4.5	2020
74.284	59.99371	48.1592	Inequality	0.005106	0.003793	SSP4 - 4.5	2030
74.67402	63.11034	40.06832	Inequality	0.004275	0.003192	SSP4 - 4.5	2040
76.34014	63.68359	29.19299	Inequality	0.003625	0.002767	SSP4 - 4.5	2050
77.51243	61.65234	18.92858	Inequality	0.003158	0.002448	SSP4 - 4.5	2060
77.84967	57.34161	10.59714	Inequality	0.002808	0.002186	SSP4 - 4.5	2070
78.6912	54.75981	8.997759	Inequality	0.002588	0.002037	SSP4 - 4.5	2080
79.22868	50.37393	7.130474	Inequality	0.002404	0.001905	SSP4 - 4.5	2090
79.36715	44.4841	4.697732	Inequality	0.002234	0.001773	SSP4 - 4.5	2100
			Inequality - A Road Divided			SSP4 - 6.0	2005
77.43486	47.0715	49.97054	Inequality	0.007599	0.005884	SSP4 - 6.0	2010
75.84824	54.16237	57.63439	Inequality	0.006258	0.004747	SSP4 - 6.0	2020
73.74097	57.22373	63.57748	Inequality	0.005347	0.003943	SSP4 - 6.0	2030
73.45851	60.68043	61.97077	Inequality	0.00458	0.003364	SSP4 - 6.0	2040
73.79947	63.08057	56.52422	Inequality	0.004015	0.002963	SSP4 - 6.0	2050
74.21943	63.82191	49.33873	Inequality	0.003594	0.002668	SSP4 - 6.0	2060
75.47724	63.71131	40.15679	Inequality	0.003208	0.002421	SSP4 - 6.0	2070
77.99471	62.1529	30.4646	Inequality	0.002845	0.002219	SSP4 - 6.0	2080
80.39996	58.70827	21.06467	Inequality	0.00254	0.002042	SSP4 - 6.0	2090
82.42321	53.8546	13.17839	Inequality	0.002289	0.001887	SSP4 - 6.0	2100
77.87534	43.50631	43.35295	Inequality	0.00813	0.006331	SSP4 - Base	2005
77.43486	47.0715	49.97054	Inequality	0.007599	0.005884	SSP4 - Base	2010
75.42972	52.39303	61.11613	Inequality	0.006389	0.004819	SSP4 - Base	2020
72.97081	56.35663	65.39404	Inequality	0.005434	0.003965	SSP4 - Base	2030
72.37758	59.3894	64.88929	Inequality	0.004686	0.003392	SSP4 - Base	2040
72.50499	61.18852	60.96774	Inequality	0.004132	0.002996	SSP4 - Base	2050
72.6395	61.6889	56.02199	Inequality	0.003732	0.002711	SSP4 - Base	2060
73.61966	61.62037	49.51178	Inequality	0.003365	0.002477	SSP4 - Base	2070
75.61954	59.99508	43.32791	Inequality	0.00303	0.002291	SSP4 - Base	2080
77.0818	57.5097	37.25615	Inequality	0.002771	0.002136	SSP4 - Base	2090
78.21898	54.76594	32.0499	Inequality	0.002566	0.002007	SSP4 - Base	2100
71.17951	48.46	36.6	Fossil-fuel	0.008195	0.005833	SSP5 - 1.9	2005
70.89716	50.06	41.06	Fossil-fuel	0.00744	0.005275	SSP5 - 1.9	2010
72.73314	49.15	30.63	Fossil-fuel	0.006082	0.004424	SSP5 - 1.9	2020
77.37032	35.31	13.33	Fossil-fuel	0.00392	0.003033	SSP5 - 1.9	2030
77.29992	21.58	6.191	Fossil-fuel	0.002508	0.001939	SSP5 - 1.9	2040

71.68067	12.3	3.486	Fossil-fuel	0.00211	0.001512	SSP5 - 1.9	2050
70.46106	5.776	1.428	Fossil-fuel	0.001743	0.001228	SSP5 - 1.9	2060
71.25971	2.513	1.163	Fossil-fuel	0.001541	0.001098	SSP5 - 1.9	2070
71.96486	1.05	1.073	Fossil-fuel	0.001393	0.001002	SSP5 - 1.9	2080
73.25897	0.8238	0.8616	Fossil-fuel	0.001259	0.000922	SSP5 - 1.9	2090
74.07509	0.6644	0.7162	Fossil-fuel	0.001137	0.000843	SSP5 - 1.9	2100
71.17951	48.46	36.6	Fossil-fuel	0.008195	0.005833	SSP5 - 2.6	2005
70.89716	50.06	41.06	Fossil-fuel	0.00744	0.005275	SSP5 - 2.6	2010
72.73314	49.15	30.63	Fossil-fuel	0.006082	0.004424	SSP5 - 2.6	2020
76.18038	36.24	14.75	Fossil-fuel	0.004295	0.003272	SSP5 - 2.6	2030
78.56076	23.07	7.691	Fossil-fuel	0.002894	0.002273	SSP5 - 2.6	2040
76.23483	14.21	5.413	Fossil-fuel	0.002321	0.001769	SSP5 - 2.6	2050
71.52393	7.563	3.276	Fossil-fuel	0.001938	0.001386	SSP5 - 2.6	2060
71.12014	4.211	2.845	Fossil-fuel	0.001622	0.001154	SSP5 - 2.6	2070
72.06164	2.828	2.839	Fossil-fuel	0.001412	0.001017	SSP5 - 2.6	2080
72.3546	2.665	2.713	Fossil-fuel	0.001279	0.000925	SSP5 - 2.6	2090
72.49781	2.424	2.493	Fossil-fuel	0.00117	0.000848	SSP5 - 2.6	2100
71.17951	48.46	36.6	Fossil-fuel	0.008195	0.005833	SSP5 - 3.4	2005
70.89716	50.06	41.06	Fossil-fuel	0.00744	0.005275	SSP5 - 3.4	2010
72.73314	49.15	30.63	Fossil-fuel	0.006082	0.004424	SSP5 - 3.4	2020
75.41574	38.07	19.4	Fossil-fuel	0.004379	0.003302	SSP5 - 3.4	2030
77.64706	26.54	12.89	Fossil-fuel	0.003057	0.002374	SSP5 - 3.4	2040
77.45425	17.49	9.316	Fossil-fuel	0.002445	0.001894	SSP5 - 3.4	2050
74.32662	10.27	5.923	Fossil-fuel	0.002038	0.001515	SSP5 - 3.4	2060
72.69406	5.55	4.271	Fossil-fuel	0.001688	0.001227	SSP5 - 3.4	2070
73.02326	3.783	3.783	Fossil-fuel	0.001447	0.001056	SSP5 - 3.4	2080
73.63469	3.875	4.317	Fossil-fuel	0.00128	0.000942	SSP5 - 3.4	2090
74.18584	3.692	4.657	Fossil-fuel	0.001145	0.00085	SSP5 - 3.4	2100
71.17951	48.46	36.6	Fossil-fuel	0.008195	0.005833	SSP5 - 4.5	2005
70.89716	50.06	41.06	Fossil-fuel	0.00744	0.005275	SSP5 - 4.5	2010
72.73314	49.15	30.63	Fossil-fuel	0.006082	0.004424	SSP5 - 4.5	2020
75.26808	39.58	20.75	Fossil-fuel	0.004411	0.00332	SSP5 - 4.5	2030
77.36247	28.95	17.19	Fossil-fuel	0.003141	0.00243	SSP5 - 4.5	2040
76.81947	20.35	12.39	Fossil-fuel	0.002576	0.001979	SSP5 - 4.5	2050
73.99024	13.64	9.248	Fossil-fuel	0.002197	0.001625	SSP5 - 4.5	2060
72.51381	8.381	7.024	Fossil-fuel	0.001842	0.001336	SSP5 - 4.5	2070
73.50263	6.209	6.216	Fossil-fuel	0.00158	0.001161	SSP5 - 4.5	2080
75.03419	5.438	6.165	Fossil-fuel	0.001355	0.001017	SSP5 - 4.5	2090
76.13934	4.437	6.142	Fossil-fuel	0.001206	0.000918	SSP5 - 4.5	2100
71.17951	48.46	36.6	Fossil-fuel	0.008195	0.005833	SSP5 - 6.0	2005
70.89716	50.06	41.06	Fossil-fuel	0.00744	0.005275	SSP5 - 6.0	2010
72.73314	49.15	30.63	Fossil-fuel	0.006082	0.004424	SSP5 - 6.0	2020
74.49318	39.19	25.41	Fossil-fuel	0.004563	0.003399	SSP5 - 6.0	2030
75.70892	30.28	26.77	Fossil-fuel	0.0034	0.002574	SSP5 - 6.0	2040
74.81481	23.47	22.89	Fossil-fuel	0.002841	0.002126	SSP5 - 6.0	2050
71.91453	17.78	16.7	Fossil-fuel	0.002478	0.001782	SSP5 - 6.0	2060
71.71888	12.9	12.81	Fossil-fuel	0.002088	0.001497	SSP5 - 6.0	2070

73.73041	10.02	10.11	Fossil-fuel	0.00175	0.00129	SSP5 - 6.0	2080
75.50781	7.862	7.862	Fossil-fuel	0.001471	0.00111	SSP5 - 6.0	2090
76.51976	6.603	6.752	Fossil-fuel	0.00129	0.000987	SSP5 - 6.0	2100
71.17951	48.46	36.6	Fossil-fuel	0.008195	0.005833	SSP5 - Base	2005
70.89716	50.06	41.06	Fossil-fuel	0.00744	0.005275	SSP5 - Base	2010
71.87301	49.33	32.12	Fossil-fuel	0.006151	0.004421	SSP5 - Base	2020
72.85968	39.62	28.2	Fossil-fuel	0.004762	0.00347	SSP5 - Base	2030
72.99846	31.11	32.66	Fossil-fuel	0.003749	0.002737	SSP5 - Base	2040
71.59829	25.01	30.33	Fossil-fuel	0.003208	0.002297	SSP5 - Base	2050
67.94798	20.72	23.06	Fossil-fuel	0.002894	0.001966	SSP5 - Base	2060
65.10152	16.04	17.83	Fossil-fuel	0.002602	0.001694	SSP5 - Base	2070
63.82488	12.48	13.51	Fossil-fuel	0.002344	0.001496	SSP5 - Base	2080
63.56546	9.746	9.876	Fossil-fuel	0.002034	0.001293	SSP5 - Base	2090
63.98026	6.99	7.858	Fossil-fuel	0.001769	0.001132	SSP5 - Base	2100

CO2 emissions converted to MMtCO2	Mauna Loa CO2		Natl Fossil C Emissions from GCP 2023		...converted to MMtCO2	3.67
29,394.2	1959	315.98	1970	4.066354923	14250.12951	EIA 20
31,981.5	1960	316.91	1971	4.231401397	14828.51819	
30,554.1	1961	317.64	1972	4.428110439	15517.86513	Internatio
17,442.7	1962	318.45	1973	4.662962036	16340.87879	Release d
5,342.8	1963	318.99	1974	4.642759739	16270.08189	
1,609.8	1964	319.62	1975	4.654135542	16309.94724	Table A10
-317.0	1965	320.04	1976	4.909692158	17205.51955	million me
-2,441.2	1966	321.37	1977	5.04875388	17692.84729	Region
-5,286.8	1967	322.18	1978	5.204500693	18238.64624	Americas
-8,181.2	1968	323.05	1979	5.351806848	18754.86576	United S
-11,956.1	1969	324.62	1980	5.318920417	18639.61859	Canada
29,394.2	1970	325.68	1981	5.191840824	18194.28101	Mexico
31,981.5	1971	326.32	1982	5.150408817	18049.08673	Brazil
35,748.0	1972	327.46	1983	5.183381668	18164.63675	Other Ar
33,774.3	1973	329.68	1984	5.362391217	18791.95761	Europe an
26,247.5	1974	330.19	1985	5.543641273	19427.1301	Western
19,333.1	1975	331.13	1986	5.626354583	19716.99053	Russia
13,000.1	1976	332.03	1987	5.79969285	20324.43695	Eastern I
7,288.2	1977	333.84	1988	6.027600986	21123.11796	Asia Pacif
-474.7	1978	335.41	1989	6.109890141	21411.49198	Japan
-6,002.1	1979	336.84	1990	6.2033265	21738.93025	South Ke
-5,455.4	1980	338.76	1991	6.328084455	22176.13188	Australia
29,394.2	1981	340.12	1992	6.148518568	21546.86139	China
31,981.5	1982	341.48	1993	6.210640553	21764.56161	India
36,882.5	1983	343.15	1994	6.275367603	21991.39101	Other As
38,624.1	1984	344.87	1995	6.422511737	22507.04274	Africa and
37,437.3	1985	346.35	1996	6.620678889	23201.49948	Africa
34,600.8	1986	347.61	1997	6.659908762	23338.9766	Middle E
30,959.7	1987	349.31	1998	6.633126996	23245.12261	World
23,490.1	1988	351.69	1999	6.78322262	23771.11754	Data sour
13,161.4	1989	353.2	2000	6.962487117	24399.33184	r_230822
1,222.9	1990	354.45	2001	7.015909784	24586.54617	Note: Tot
-3,862.3	1991	355.7	2002	7.171634478	25132.26761	
29,394.2	1992	356.54	2003	7.551716646	26464.22712	
31,981.5	1993	357.21	2004	7.814548562	27385.29499	
36,878.3	1994	358.96	2005	8.082531141	28324.41283	
39,609.2	1995	360.97	2006	8.359278412	29294.24565	

40,999.6	1996	362.74	2007	8.606616821	30161.01808
41,131.8	1997	363.88	2008	8.753875153	30677.07001
39,869.3	1998	366.84	2009	8.60860315	30167.97897
34,822.1	1999	368.54	2010	9.103685437	31902.94477
27,142.3	2000	369.71	2011	9.417177434	33001.54576
19,869.7	2001	371.32	2012	9.552407299	33475.44515
14,046.6	2002	373.45	2013	9.634731399	33763.94163
29,394.2	2003	375.98	2014	9.675244199	33905.91464
31,981.5	2004	377.7	2015	9.662908562	33862.68565
36,892.2	2005	379.98	2016	9.666117925	33873.93253
39,680.3	2006	382.09	2017	9.822570381	34422.20434
41,860.8	2007	384.02	2018	10.02467974	35130.47615
42,668.6	2008	385.83	2019	10.12671339	35488.04275
43,038.3	2009	387.64	2020	9.586933986	33596.44043
40,936.4	2010	390.1	2021	10.09599789	35380.40339
35,332.5	2011	391.85	2022	10.1784488	35669.34426
30,633.4	2012	394.06	2023	10.31429277	36145.39571
27,049.0	2013	396.74	2025		36,053
30,872.7	2014	398.82	2030		36,726
33,151.9	2015	401.02	2035		37,724
36,454.6	2016	404.41	2040		38,497
22,911.5	2017	406.77	2045		39,685
13,019.8	2018	408.72	2050		40,954
6,064.4	2019	411.66			
1,875.6	2020	414.21			
-2,972.9	2021	416.41			
-6,872.4	2022	418.53			
-8,159.5	2023	421.08			
-8,886.6					
30,875.9					
33,132.9					
36,219.2					
31,750.8					
26,208.5					
18,325.2					
12,620.9					
5,288.1					
214.7					
-2,646.3					
-4,570.6					
30,875.9					
33,132.8					
36,374.4					
37,890.8					
36,303.4					
33,526.9					
26,728.9					

18,553.5
11,941.2
6,617.9
3,010.9
30,875.9
33,132.9
36,614.5
39,797.2
41,313.9
42,149.9
40,998.1
36,823.8
29,625.2
20,028.0
13,915.1
30,875.8
33,132.8
36,733.0
41,457.9
45,673.4
50,303.8
54,122.1
56,403.3
58,649.8
60,196.8
59,696.3
30,874.0
33,133.2
37,148.0
42,507.3
47,740.7
53,614.5
59,467.1
65,089.4
74,068.0
81,276.9
86,165.8
29,596.1
32,480.0
39,493.3
42,677.4
29,327.2
21,171.7
14,495.7
8,290.3
3,568.9
-396.5

-3,347.2
29,596.1
32,480.0
39,493.3
44,837.6
39,322.9
33,453.6
22,896.7
17,228.4
14,329.0
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6,260.1
29,596.1
32,480.0
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45,038.0
43,900.3
43,170.5
43,682.8
39,840.7
35,043.5
31,325.7
28,617.2
29,596.1
32,637.7
41,088.3
49,158.9
55,239.4
60,206.5
64,222.7
68,480.6
72,728.2
77,572.2
82,558.8
0.0
32,647.0
38,639.0
24,755.4
16,421.5
9,512.7
1,645.0
-6,162.6
-13,540.5
-20,062.8
-27,729.3
0.0
32,647.0

38,639.0
36,025.5
29,180.1
20,523.6
12,739.3
5,007.9
-3,082.7
-10,817.3
-17,439.4
0.0
32,647.0
38,639.0
39,924.6
37,337.7
30,044.9
21,167.7
13,312.6
11,488.4
9,928.1
6,446.8
0.0
32,647.0
38,639.0
45,160.9
47,483.6
47,525.2
46,201.0
43,627.6
37,408.8
30,242.0
22,476.4
29,385.7
32,647.0
40,417.5
47,694.3
51,591.2
53,078.3
53,692.0
52,929.9
49,420.8
46,575.2
44,329.3
29,547.0
32,200.0
38,379.0
36,127.0
17,732.0

-3,893.0
-14,157.0
-17,109.9
-18,634.4
-19,447.7
-20,109.0
29,547.0
32,200.0
38,379.0
41,616.0
35,771.0
21,153.0
3,784.0
-6,229.0
-12,422.0
-17,001.2
-19,178.6
29,547.0
32,200.0
38,379.0
43,098.0
42,635.2
36,800.7
26,140.0
12,998.0
612.0
-9,651.0
-13,860.7
29,547.0
32,200.0
38,379.0
43,565.0
45,133.1
42,907.6
36,203.7
28,504.4
22,986.9
16,906.0
15,843.9
29,547.0
32,200.0
38,379.0
46,480.0
53,377.0
58,061.2
58,933.6
55,217.8

50,329.9
44,092.2
40,989.4
29,547.0
32,200.0
39,548.0
51,160.0
65,836.0
82,130.0
101,151.2
117,738.5
129,647.2
130,892.9
127,628.0

3504.398849

23 Projections by region (MMT of CO2, not carbon)

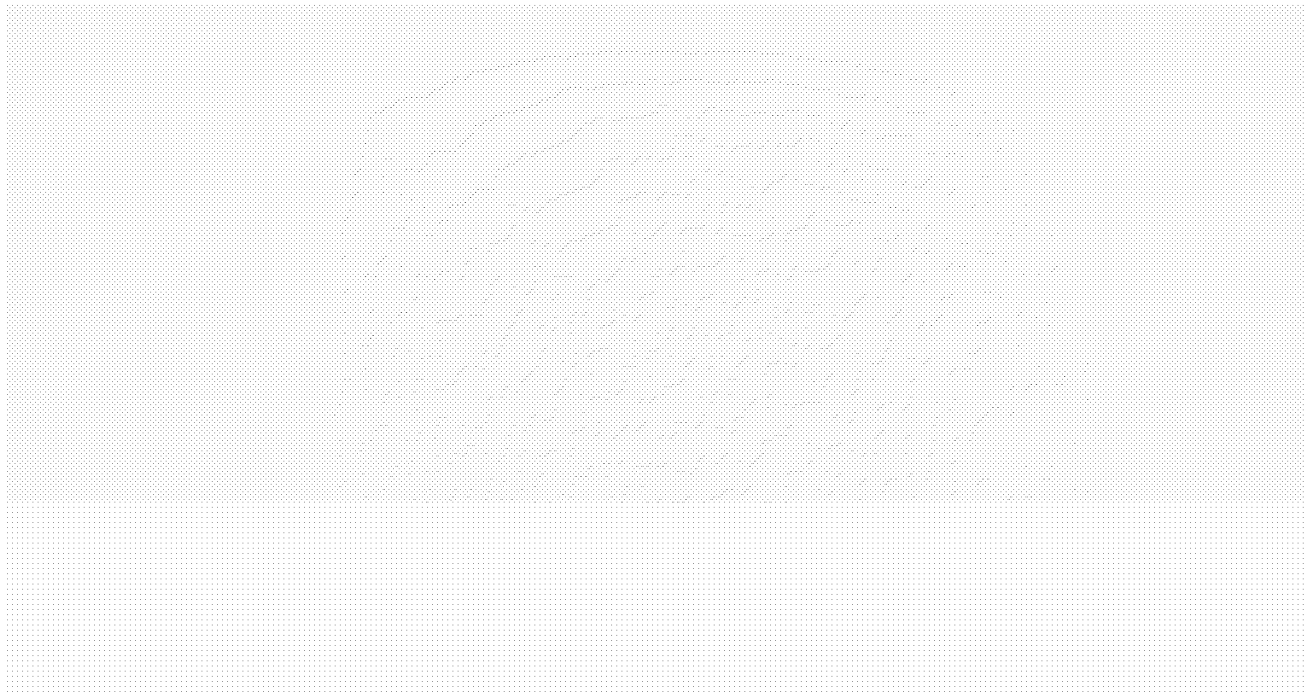
2022 U.S. number update from April 2024 report, Table 2: <https://www.eia.gov/environmental-energy-outlook-2023>
 Date: October 2023

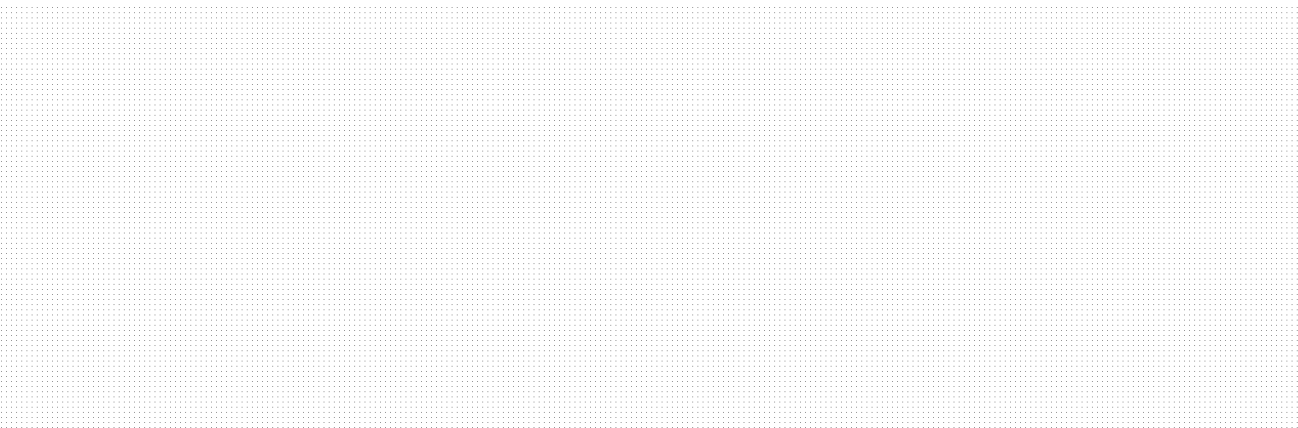
I. World carbon dioxide emissions by region, Reference case

Metric tons of carbon dioxide

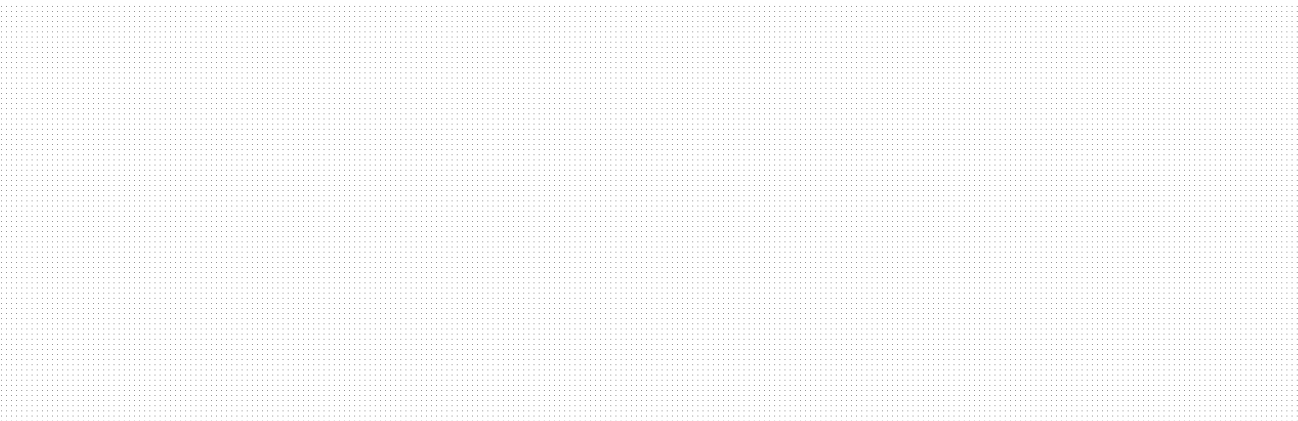
2022	2025	2030	2035	2040	2045	2050	Average annual percentage change,
6,992	6,746	6,251	6,238	6,353	6,513	6,674	-0.166%
4,941	4,542	3,999	3,891	3,865	3,896	3,938	-0.736%
548	543	516	534	562	593	624	0.462%
419	428	446	459	482	503	526	0.817%
439	467	486	490	497	498	503	0.491%
743	765	803	865	947	1,023	1,083	1.354%
6,367	6,409	6,256	6,263	6,360	6,586	6,815	0.243%
3,808	3,819	3,657	3,585	3,538	3,608	3,672	-0.130%
1,817	1,833	1,825	1,862	1,932	2,005	2,077	0.480%
742	757	774	816	891	974	1,066	1.300%
18,705	19,121	20,318	21,051	21,375	21,842	22,405	0.647%
1,039	1,019	864	821	782	762	739	-1.210%
639	649	649	648	641	636	630	-0.051%
404	395	422	433	438	449	461	0.473%
11,500	11,530	11,644	11,594	11,150	10,788	10,601	-0.290%
2,447	2,677	3,408	3,860	4,328	4,807	5,210	2.736%
2,676	2,851	3,331	3,695	4,035	4,401	4,765	2.081%
3,606	3,776	3,900	4,172	4,408	4,744	5,060	1.218%
1,331	1,380	1,504	1,697	1,837	2,066	2,283	1.945%
2,275	2,396	2,397	2,474	2,571	2,678	2,777	0.716%
35,669	36,053	36,726	37,724	38,497	39,685	40,954	0.495%

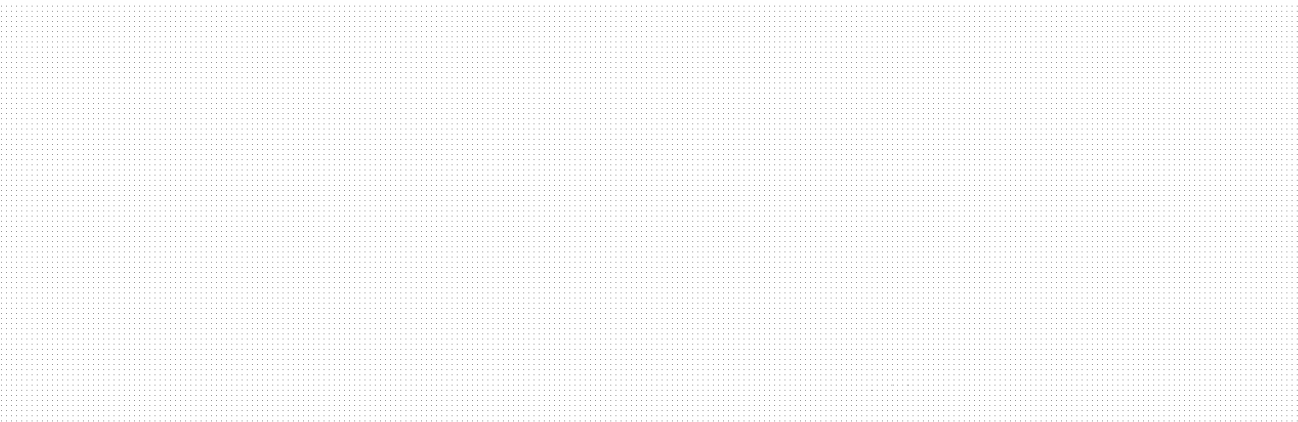
Source: U.S. Energy Information Administration, World Energy Projection System (2023), run 081459 and Annual Energy Outlook 2023 (March 2023), www.eia.gov/aeo
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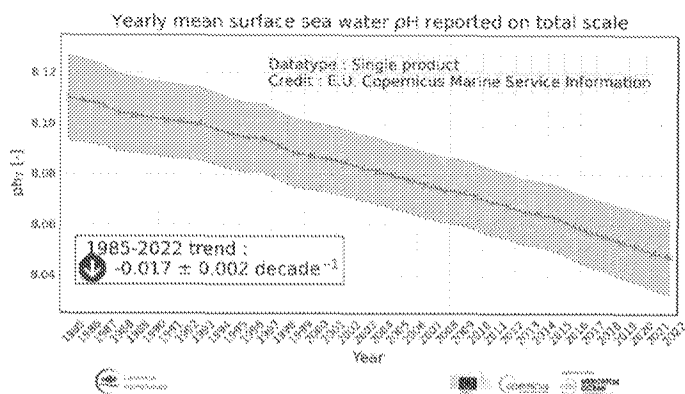




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3. Increasing CO₂ and the Alkaline Oceans

The modern-day global average pH of sea water is estimated to be 8.1, down from an estimated value of 8.2 in pre-Industrial times (Gattuso and Hansson, 2011).³ As CO₂ concentrations in the atmosphere increase, more is absorbed by the oceans. Depending upon the alkalinity (buffering capacity) of the oceans, the oceans are expected to become somewhat less alkaline over time, putatively explaining the decrease in pH from 8.2 to 8.1 over the last few hundred years.



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While this process is often called “ocean acidification”, this is a misnomer because the oceans are not expected to become acidic (pH less than 7.0); “ocean neutralization” would be more accurate. And even if the water were to turn acidic, that was to happen, it is believed that life in the oceans evolved during a period when the oceans were mildly acidic with a pH of 6.5 to 7.0 (Kriessens-Totton et al., 2018).

For many years it had long been assumed that a decreasing pH of sea water would reduce the calcification rate of coral reefs. But coral reefs already endure large swings in pH, partly due to daily photosynthetic activity in the reef; measured pH values. This results in pH values that have been measured to range from 9.4 during the day to 7.5 at night (Revelle and Fairbridge, 1957).

In 2009 it was reported that a portion of Australia’s Great Barrier Reef (GBR, the world’s largest coral reef ecosystem) had experienced a 14% decline in calcification since 1990 (De’ath et al., 2009). This was tentatively attributed to increasing water temperature and decreasing pH of sea water. But since that time, the initial 2009 report of reduced calcification rates in the GBR was reported was shown to have been the result of a biased data analysis (Ridd et al., 2013) which, when corrected, and correction for this bias led to showed no change in calculated calcification rates. Nevertheless, the alarm produced by the original paper has persisted as evidenced by the large number of published

³ A neutral aqueous solution has a pH of 7.0, while one with pH > 7.0 is basic and pH < 7 is acidic.

citations (541) received by the original study as compared to only 11 citations for the subsequent study (as of 30 April 2025).

Given the reported declines in GBR ~~coverage~~ ~~acidification~~ between 1990 and 2009, it has come as a surprise that the decline reversed over the last decade or so, with Woods Hole Oceanographic Institution asking, "*Is the Great Barrier Reef Making a Comeback?*" (Woods Hole, 2023). The most recent annual summary of GBR conditions from the Australian Institute of Marine Science was titled, *Continued Coral Recovery Leads to 36-year Highs across Two-Thirds of the Great Barrier Reef* (AIMS, 2022). Much of the decline in the GBR before 2011 turned out to be due to intense tropical cyclone activity (Beeden et al., 2015), and recovery of the reef from storm damage takes years.

On the time scale of thousands of years, boron isotope proxy measurements of pH show that ocean pH was around 7.4 or 7.5 during the last ~~ice~~ ~~age~~ ~~glaciation~~ (up to about 20,000 years ago) increasing to present-day values ~~when as~~ the world warmed during deglaciation (Rae et al., 2018). Thus, there appears to be considerable resilience of ocean biota to natural long-term changes in ocean pH since marine organisms are exposed to wide ranges in pH anyway.

It is being increasingly recognized that publication bias (alarming ocean acidification results preferred by high-impact research publications) ~~leads to exaggerated impacts from more alkaline oceans~~ ~~exaggerates the impacts of declining ocean pH~~. An ICES Journal of Marine Science Special Issue addressed this problem with an article entitled, *Towards a Broader Perspective on Ocean Acidification Research*. In the Introduction to that Special Issue, H. I. Browman stated, "As is true across all of science, studies that report no effect of ocean acidification are typically more difficult to publish." (Browman, 2016)

~~Similarly, a meta-analysis of the negative effects of ocean acidification on reef fishes found that initially dramatic conclusions published in the scientific literature were all but refuted upon subsequent analysis involving larger sample sizes of data (Clements et al., 2021).~~

In conclusion, it is becoming increasingly apparent that the effect of ocean "acidification" on marine biota has likely been exaggerated.

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2 CO₂ fertilization and global greening

The growing CO₂ concentration in the atmosphere has the important positive effect of promoting plant growth by enhancing photosynthesis and improving water use efficiency. That is evident in the "global greening" phenomenon discussed below, as well as in the improving agricultural yields discussed in Section XX.

MOVED SECTION

2.1 CO₂ and global greening

"Greening" refers to an increase in the total amount fraction of the Earth's surface covered in by plants. The main measure of greening is ~~it can be quantified by the "Leaf Area Index" or (LAI) as measured by satellite. Many studies over the past decade have confirmed a global greening pattern (rising increase in LAI) attributable to rising CO₂ levels. Zhu *et al.* (2016) was one of the first studies to report that global greening was detectable from space using satellite sensors. On data spanning from 1982 to 2011 they detected greening over 25-50% of the Earth versus "browning" over only 4%, and they attributed 70% of the greening to rising CO₂ levels (see Figure 2.3).~~

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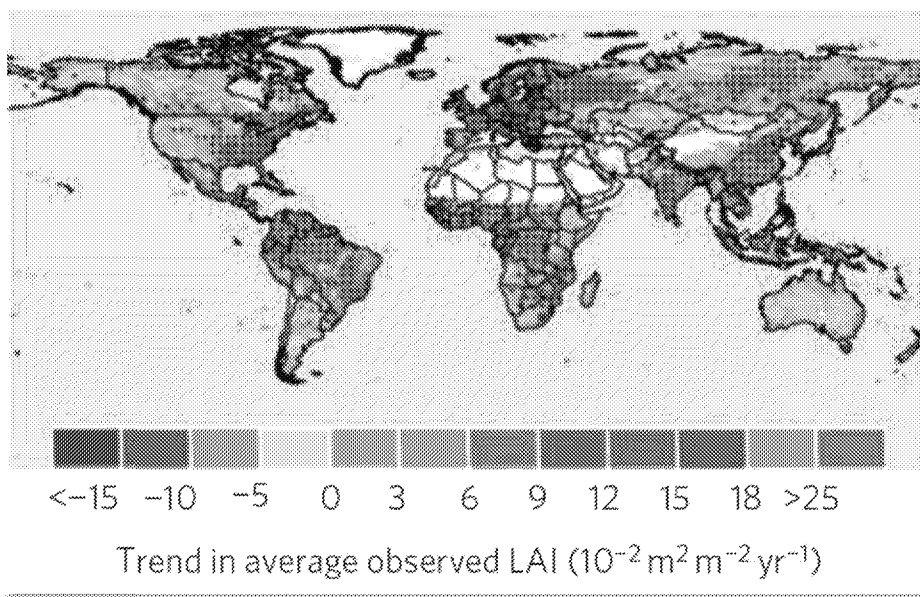


Figure 2.3: Trends in average Leaf Area Index (LAI). Source: Zhu et al. 2016 Figure 3.

Zheng (2017) confirmed the pattern, noting that greening over 30 thirty years had added 8% to global leaf area and that greening was mitigating warming. Greening has been observed globally but Chen et al. (2019) noted that China and India were taking particular advantage of exploiting it though land management changes. Thus while China accounts for only 6.6% of global vegetated area it accounts for 25% of global net increase in LAI. Piao *et al.* (2020) noted that greening was even observable in the Arctic.

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While plant models predict increases in photosynthesis should be observed in response to rising CO₂, Haverd et al. (2020) reported that observed CO₂ fertilization rate was nearly double what models had predicted. That is, CO₂ fertilization had driven an increase in observed global photosynthesis by 30% since 1900, versus 17% predicted by plant models. Among other things this indicates that global models of the socioeconomic impacts of climate change have likely understated the benefits to crops and agriculture from rising CO₂. The connection between CO₂ fertilization and climate policy will be discussed in Chapter XX.

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Finally, Chen *et al.* surveyed claims that greening had slowed down since 2000 due to drought stress. They found instead that claims of slowed greening could be attributed to faulty satellite sensors were the cause and that the corrected data Once the data were corrected they found showed accelerated greening was accelerating over 55% of the world globe while browning was accelerating over only 7% of the world. In other words, Overall the greening trend was continuing continued with no evidence of slowdown, and CO₂ fertilization remained the dominant driver

2.2 Photosynthesis and CO₂ levels

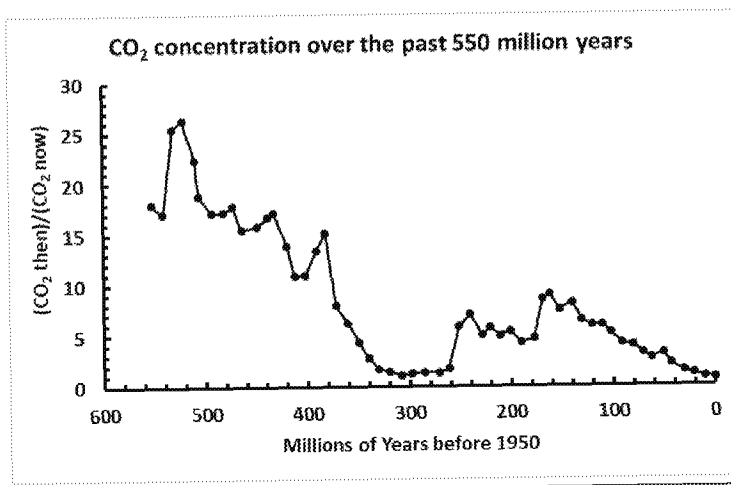
A key direct effect of adding CO₂ to the atmosphere is its positive effect on plant life via enhancement of photosynthesis and improvement to plant water use efficiency.

The term photosynthesis describes the process by which plants build biomass through photosynthesis, a process that converts. The process requires carbon dioxide (CO₂), water (H₂O), and light into sugar. The plant enzyme responsible for photosynthesis is called Ribulose-1,5-bisphosphate-carboxylase/oxygenase or "Rubisco". Photosynthesis is initiated when CO₂ is available at the surface of the RuBisCo enzyme where it is converted to a molecule with 3 carbon atoms and thereafter incorporated into plant mass. This, which is referred to as the "C3" process.

Rubisco is estimated to have evolved about 3 billion years ago. Over geological time the Earth's atmospheric CO₂ levels were usually much higher than they are today, as shown in the following figure

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About 400 million years ago CO₂ levels were an estimated 2,000-4,000 ppm and were at or above 1,000 ppm for much of the interval from 200 to 50 million years ago (Berner 2006, Judd et al. 2024). Over the past 35 million years the level of atmospheric CO₂ has been steadily declining. During glaciations levels have fallen as low as 170 ppm (Gerhart and Ward 2010).

In response to low-CO₂ conditions some plants evolved another photosynthetic pathway called C₄, in which CO₂ is concentrated in the vicinity of Rubisco allowing for the C₃ process to function more efficiently. For agricultural purposes the plant categories are:

- C₃: rice, wheat, soybeans and most other crops
- C₄: maize (corn), sugar cane, millet, sorghum

Had atmospheric CO₂ levels continued declining, plant growth rates would have declined and eventually ceased. Below 180 ppm many C₃ species experience growth rate reductions on the order of 40-60% compared to their growth rates at 350 ppm (Gerhart and Ward 2010). C₃ plants have been observed under experimental conditions to stop growing altogether at levels between 60—140 ppm CO₂. Some C₄ plants are still able to grow at levels even as low as 10 ppm, albeit very slowly (Gerhart and Ward 2010).

Currently, CO₂ levels are about 420 ppm, up from 280 ppm in the early 1800s. The positive response of plants to extra CO₂ is illustrated in Figure 1 which is reproduced from Gerhart and Ward (2010). It shows the growth effect of CO₂ on Velvetleaf (*Abutilon theophrasti*) seedlings over 14 days under controlled conditions where only the CO₂ exposure is varied. The gains exhibited from increasing CO₂ from 150 ppm to 350 ppm continue under a further doubling to 700 ppm.

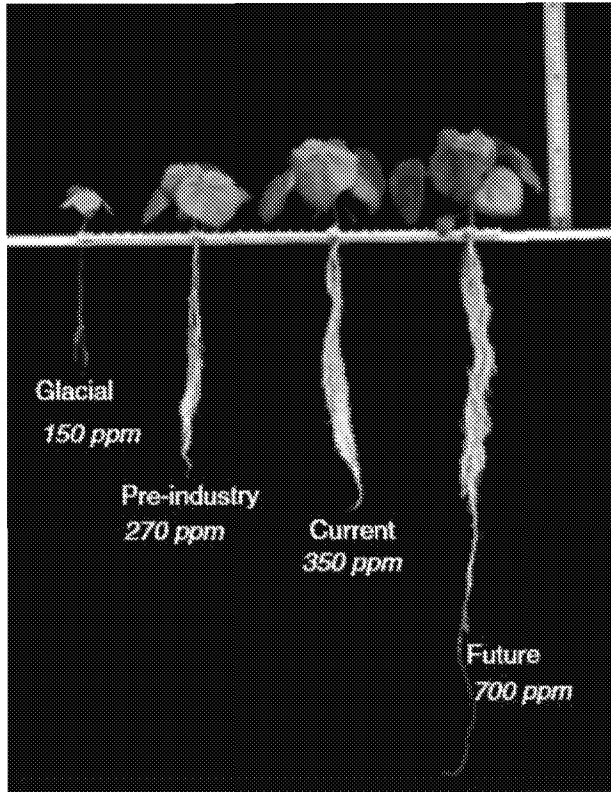


Figure 2.1: growth of *Abutilon theophrasti* after 14 days under identical conditions but for the indicated variations in CO₂ levels. Source: Gerhart and Ward (2010).

Over the past 60+ years there have been tens of thousands of studies on the response of plants to rising CO₂ levels. The overwhelming theme is that plants, especially C3 plants, benefit from extra CO₂. There are two mechanisms by which CO₂ confers a growth benefit:

- Enhanced photosynthesis via the metabolic pathways described above.
- Increased water use efficiency. This arises because plants draw in CO₂ by opening the stomata (pores) on the leaf surface. When CO₂ is scarce the stomata must be kept wide open for long periods, which allows water to evaporate away. Under enriched CO₂ conditions the stomata are closed for longer periods helping the plant retain water longer, thereby increasing water use efficiency.

One of the ways in which scientists have studied the effects of CO₂ enrichment is through “free air enrichment experiment” or FACE plots, in which small chimneys are placed in fields surrounding plants and the growth response to elevated CO₂ under varying weather conditions are recorded. Ainsworth and Long (2021) summarize results from about 250 such studies. They conclude:

- “Across 186 independent studies of 18 C3 crops, elevation of [CO₂] by ca. 200 ppm caused a ca. 18% increase in yield under non-stress conditions.”
- “Legumes and root crops showed a greater increase and cereals less. Nitrogen deficiency reduced the average increase to 10%, as did warming by ca. 2°C.”

The authors reported that C4 plants mainly exhibited benefits during drought conditions. However additional evidence on corn growth under enhanced CO₂ levels will be provided below in Section XX.

2.2 CO₂ and key global food crops—I DON’T THINK THIS SECTION IS NEEDED]

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Rice

Ly (2020) analyzed experimental studies done on conventional rice plants in Japan and China. They found that the type of cultivar was a determining factor in quantifying the amount of response displayed, but all cultivar types showed positive yield response to elevated CO₂ levels. An additional 200 ppm CO₂ raised rice yields by 13.5%-32.8% for three common rice cultivars. A similar meta-analysis synthesis (Hu, 2021) was done for all available FACE studies on rice. On average, elevated CO₂ enhanced rice yields by 16.2% and improved their leaf photosynthesis. Hybrid rice displayed a greater yield enhancement (24.7%) than conventional rice (14.2%). The synthesis also revealed that yield response to elevated CO₂ was constrained by changes in nitrogen availability and temperatures. Ainsworth and Long (2021) argued that if farmers are careful in choosing the rice variety with the highest yield potential, they will show as much as 35% yield increase from an extra 200 ppm CO₂ compared to 14% without adaptation.

Potatoes

Lee (2020) grew potato plants under elevated CO₂ concentration and reported they “yielded a distinct increase in growth and development and canopy net photosynthetic rate during tuber initiation and bulking. Consequently, biomass and canopy net photosynthesis increased, and tuber yield increased by 20.3%. The CO₂Science.org website reports on 33 published experiments between 1988 and 2019 exposing potatoes to enriched CO₂ levels. Converted to a common +300ppm scale the average photosynthesis rate change was +50.3 percent.

Soybean

Studies on the impact of elevated CO₂ on Soybean (*Glycine max* (L.) Merr.) plants in the water-deficient region of Huang-Huai-Hai Plain, China, showed that elevated CO₂ concentrations resulted in improved photosynthesis rate, water use efficiency and growth (Li, 2013) under both normal conditions and drought conditions. The CO₂Science.org website reports on 108 published experiments between 1985 and 2019 exposing soybean to enriched CO₂ levels. Converted to a +300ppm common scale the average growth benefit was +50.9 percent. In addition there were 10 studies reporting on +600 ppm CO₂ enrichment, resulting in an average increase in photosynthesis of 90.3%.

Maize (corn)

The CO₂Science.org website reports on 28 published experiments between 1983 and 2018 exposing corn (*Zea mays* L.) to enriched CO₂ levels. Converted to a +300ppm common scale the average growth benefit was +23.7 percent. Corn also benefits from increased drought tolerance under elevated CO₂. An experimental study (Allen Jr, 2011) exposed plants to water stress conditions in sunlit controlled-

environment chambers at 360 ppm (ambient) and 720 ppm (elevated) CO₂. The drought stress caused a 41% loss of growth under ambient CO₂ but only a 13% loss under elevated CO₂.

Wheat

The CO₂Science.org website reports on 92 published experiments between 1983 and 2020 exposing common wheat (*Triticum aestivum* L.) to enriched CO₂ levels. Converted to a +300ppm common scale the average growth benefit was +67.6 percent. Blandino (2020) measured the yield as well as nutritional quality of an “improver” hybrid wheat variety and its parents under elevated CO₂ levels (+166 ppm). They reported a grain yield increase of +16% but a 7% decrease in grain protein levels. But they found that the food quality of different wheat varieties responded differently to elevated CO₂ levels, so that with proper varietal selection end-users can select wheat types that best take advantage of the elevated CO₂.

Coffee

The CO₂Science.org website reports on 18 published experiments between 2013 and 2020 exposing coffee (*Coffea arabica*) to enriched CO₂ levels. Converted to a +300ppm common scale the average growth benefit was +110.9 percent. To forecast the future impact of climate on coffee yields, Verhage (2017) analyzed yield data over 1989 to 2013 from 42 municipalities in Brazil. The study found that “yield losses due to high air temperatures and water deficit will increase, while losses due to frost will decrease. Nevertheless, extra losses are offset by the CO₂ fertilization effect, resulting in a net increase of the average Brazilian Arabica coffee yield of 0.8% to 1.48 t ha⁻¹ in 2040-2070”.

Specific effects of climate change on US agriculture will be reviewed in Chapter XX.

2.3 Rising CO₂ and crop water use efficiency

Deryng *et al.* (2016) surveyed evidence on crop water productivity (CWP), i.e., the yield per unit of water used, drawing attention to the potential for CO₂ both to enhance photosynthesis and reduce leaf-level transpiration (water loss during leaf respiration). They surveyed all available FACE data on crop yield changes for Maize (corn), Wheat, Rice and Soybean, and combined it with crop model data simulating yield responses as of 2080 under the extreme RCP8.5 scenario in four growing regions (Tropics, Arid, Temperate and Cold) each of which were split into rainfed and irrigated sub-regions. In every region they reported that models without CO₂ fertilization predicted CWP losses but CO₂ fertilization more than offset them so that and once it was taken into account all regions showed a net CWP gain. Deryng *et al.* (2016) also reported that negative impacts of warming on wheat and soybean yields from what?? were fully offset by CWP gains, and gains and mitigated by up to 90% for rice and 60% for maize.

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Figure 2.2 shows their Deryng *et al.*'s results. The gray bars report yield changes under warming alone and the green bars show the effects of warming after accounting for the CO₂ fertilization effect.

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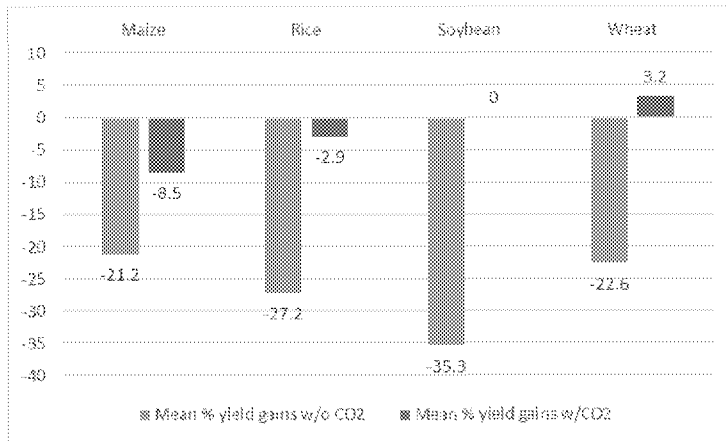


Figure 2.2: mean yield changes under RCP8.5 as of 2080 without CO₂ fertilization (gray) and with CO₂ fertilization (green). Data from Derynget al. (2016).

Similarly to this, Cheng *et al.* (2017) noted that increased global plant growth from 1982 to 2011 due to rising CO₂ uptake was accompanied by such large gains in CWP that, despite the extra biomass, global water use by plants had not increased.

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Derynget al. (2016) assumed that climate change would “exacerbate water scarcity”. It is noteworthy that while models predict drylands will expand under climate warming, current data show the opposite: greening is happening even in arid areas. Zhang et al. (2014) report that due to increased CO₂ levels “increasing aridity in drylands won’t lead to a general loss of vegetation productivity”; increased desertification will happen in at most 4% of currently arid areas.

2.5 Concealment of CO₂ fertilization benefits in IPCC Reports

If CO₂ emissions were had been discovered to be causing global crop declines and regional browning, we would almost certainly have seen it that surely would have been discussed prominently in IPCC reports, perhaps even with its and indeed it likely would have been the subject of its own chapter in an Assessment Report if not an IPCC Special Report on its own. By contrast the IPCC has been almost silent on the topic of global greening.

The topic is briefly acknowledged in a few places in the body of the IPCC 6th Assessment Report but is omitted in all Summary documents. Based on word searches here is what the most recent IPCC Summary documents (AR6) had to say about it:

Working Group I Summary for Policymakers: No mention.

~~Working Group I Technical Summary: No mention of greening. CO₂ fertilization mentioned twice: as a contributor via plant growth to the land carbon sink and as a contributor to the increased amplitude of the seasonal CO₂ cycle.~~

~~Working Group II Summary for Policymakers: No mention of greening except the observation that adding forest cover to cities can locally reduce temperatures. No mention of CO₂ fertilization.~~

~~Working Group II Technical Summary: No mention.~~

~~AR6 Synthesis Report: No mention.~~

~~AR6 Summary of Synthesis Report (called the "Longer Report"): No mention.~~

The topic is briefly acknowledged in a few places in the body of the IPCC 6th Assessment Report but is omitted in all Summary documents. For example,

Section 2.3.4.3.3 of the AR6 Working Group I report, entitled is titled "global greening and browning," ~~It~~ points out that the IPCC Special Report on Climate Change and Land had concluded with high confidence that greening had increased globally over the past 2-3 decades. It then discusses the various estimate of greening trends and, notes that there are variations in the estimates among data sets so that and then says that while they have there is high confidence that greening has occurred, they have but low confidence in the magnitude of the trend. There are also brief mentions of CO₂ fertilization effects and improvements in water use efficiency in a few other chapters in the AR6 Working Groups I and II Reports. But as noted, despite the volume of supporting evidence, news about global greening, improved plant water use efficiency and gains in crop production is omitted from the Summaries for Policymakers.

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5 Climate Sensitivity to CO₂ Forcing

5.1 Introduction

The magnitude of the sensitivity of Earth's climate—The climate's response to increasing concentrations of CO₂ is at the heart of the scientific debate on anthropogenic climate change, and so also the public debate on the appropriate policy response to increasing CO₂ in the atmosphere "climate action." The simplest measure of that response is the rise in the global average surface temperature, quantified by the Equilibrium Climate Sensitivity (ECS). ECS is defined as the amount of warming expected in response to a doubling of CO₂ from its pre-industrial concentration of 280 ppm, after all climate components have had time to adjust. Some components, like temperatures in the lower atmosphere (troposphere), adjust rapidly, while others such as the deep ocean and cryosphere might take as long as centuries. A related measure, the Transient Climate Response (TCR), better describes the shorter time scales; it is defined as the amount of warming when the CO₂ concentration is doubled by rising one percent annually for 70 years. Equilibrium Climate Sensitivity (ECS) refers to the expected amount of warming averaged over the Earth's surface in response to a doubling of CO₂, after all climate systems have had time to adjust. Some systems, like temperatures in the troposphere, adjust very rapidly, whereas others such as the deep ocean and ice sheets may take decades or even centuries. A related metric which is helpful for analysis on shorter time scales is the Transient Climate Response (TCR), defined as the amount of warming after 70 years in which atmospheric CO₂ increases by one percent annually.

In 1979 the Charney (1979) Report for the US National Academy of Sciences proposed that the most likely value for ECS was 3.0°C plus or minus 1.5°C. The ECS range between 1.5 and 4.5°C is characterized by the IPCC AR5 as the *likely* range (66 percent probability); the AR5 stated that ECS is *extremely unlikely* (95 percent probability) to be below 1.0°C and very unlikely (90 percent probability) to exceed 6.5°C. This range of ECS values has remained stubbornly wide, despite many individual studies claiming to narrow it. Most recently, the IPCC AR6 narrowed its assessment of the *likely* range of ECS to 2.5–4.0°C and the *very likely* range to be between 2.0 and 5.0°C. This narrowing of the range on the low end is disputed, as will be discussed below.

The 1979 Charney Report for the US National Academy of Sciences proposed that the most likely ECS was 3.0 ± 1.5°C. The IPCC repeatedly reaffirmed the range with only minor variations until its most recent AR6. AR5 termed 1.5 – 4.5°C as the *likely* range (66 percent probability) and stated that ECS is *extremely unlikely* (95 percent probability) to be below 1.0°C and very unlikely (90 percent probability) to exceed 6.5°C.

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The uncertainty in ECS has remained stubbornly wide, despite many individual studies that claimed to narrow it. Most recently, AR6 narrowed the *likely* range to 2.5–4.0°C and deemed the *very likely* range to be 2.0 – 5.0°C. This narrowing of the range on the low end is disputed, as will be discussed below.

Uncertainties in ECS are highly consequential for policy making. As will be discussed in Chapter 13, economic models use ECS values to project the costs of CO₂ emissions. The traditional value (3.0 °C) has typically yielded modest global social costs of CO₂ emissions, sufficient to justify some policy actions, but mostly deferred to later in this century. If ECS is very high (above 4.5°C) immediate aggressive emission controls become more imperative, whereas no CO₂ emission controls are economically justifiable for ECS below 2.0°C (Dayaratna et al. 2016, 2020). Uncertainties about ECS are highly consequential for policy making. As will be discussed in Chapter 13, economic models take the ECS value from climate science and use it to project the costs of CO₂ emissions. The traditional

ECS value (3.0 °C) has typically yielded modest global social costs of CO₂ emissions, enough to justify some policy actions though mostly deferred to later in the century. If ECS is very high (4.5°C or above) aggressive immediate emission controls become more imperative, whereas values closer to 2.0°C have been shown to imply that no CO₂ emission controls are economically justifiable (Dayaratna et al 2016, 2020). Obtaining a precise estimate is impossible, so policy making needs to account for the uncertainty.

5.2 Model-based methods of computing climate sensitivity to GHGs

The ECS range for the given in IPCC AR4 and AR5 has been obtained primarily by examining the behaviour of climate models. However, the IPCC changed course in its For the AR6 when it the IPCC changed course and turned to a more direct data-driven methodology. Here we discuss some of the pitfalls of using climate models to try to determine the Earth's climate sensitivity. However, key components of climate models include adjustable parameters and parameterization of small-scale processes such as clouds; hence the models are not dispositive of the actual climate's sensitivity. There are approximately three dozen computer climate models operated by research groups around the world (Cannon 2024). GCMs are valuable tools for understanding the climate system from a theoretical perspective. But the models have become so complex, often with 1 million or more lines of computer code (Brown Steiner 2024), that it would be prohibitively expensive and time consuming for anyone to replicate the models' projections of climate change, let alone test the myriad model approximations embedded in the computer codes; a climate model typically takes hundreds of experts many years to develop (McSweeney and Hausfather 2018). As a result, these models are published in the scientific literature with little to no independent evaluation (Pielke et al 2010). Climate modeling thus stands as an unusual class of scientific endeavor wherein researchers validating the scientific claims of others—a hallmark of science (National Academy of Science 2019)—becomes impractical, if not impossible. LACK OF FORMAL VERIFICATION AND VALIDATION IS NOT THE BIGGEST PROBLEM. I DON'T THINK THIS CHAPTER IS THE PLACE TO GO THROUGH ALL THE PHILOSOPHICAL ISSUES WITH CLIMATE MODELS, I WROTE A WHOLE CHAPTER ON THIS IN MY BOOK

THE AR6 decided that climate models are useless for determining ECS, and we can just agree with them

Climate sensitivity ECS represents is an emergent property of climate models—that is, it is not directly parameterized or tuned. However, collections of parameterizations are often chosen to produce an expected value of climate sensitivity, particularly with regards to sub-grid-scale cloud processes. Collections of parameterizations are often chosen to produce an expected value of climate sensitivity, particularly with regards to sub-grid-scale cloud processes. Otherwise plausible models and parameter selections have been discarded because of perceived conflict with this warming rate, or aversion to a model's climate sensitivity being outside an accepted range. For example, Mauritsen and Roeckner (2020) state the following regarding their Max Planck Institute climate model (emphasis added):

"We have documented how we tuned the MPI-ESM1.2 global climate model to match the instrumental record of warming; an endeavor which has clearly been successful. Due to the historical order of events, the choice was to do this practically by *targeting an ECS of about 3 K using cloud feedbacks*, [emphasis added] as opposed to tuning the aerosol forcing."

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Because of concerns about model tuning and the high sensitivity to cloud parameterizations, the IPCC AR6 (2021) did not rely on climate model simulations in their assessment of climate sensitivity, relying instead on other methods in its assessment instead, chiefly a recent empirical estimate.

5.3 Data-driven methods of computing climate sensitivity to GHGs

Climate sensitivity can also be estimated from instrumental records of surface temperatures and ocean heat content, combined with estimates of how climate forcings (e.g., greenhouse gases, solar, volcanoes, aerosols) have changed in the past (Otto et al., 2013). Using this information, a simple empirical model called an Energy Balance Model can be estimated. It requires estimating a feedback parameter whose uncertainties are highly amplified in the resulting ECS (Roe and Baker, 2007).

Commented [SK3]: There is potential for confusion here since the previous section also refers to models. Perhaps we should consistently use GCMs for the latter?

The accuracy of the data-driven methods depends on the quality of the input data. Assumptions are needed about ocean heat storage, and the ocean data is inadequate. The greatest source of uncertainty is the amount and composition of aerosol particles and their interactions with cloud radiative properties (the so-called aerosol indirect effect). Climate models exhibit warming in response to GHGs but cooling in response to aerosols (Schwartz et al. 2007). Observed 20th century warming can be shown to be consistent either with low ECS and low aerosol cooling, or high ECS and high aerosol cooling. Since fossil fuel use adds both GHGs and aerosols to the atmosphere, both effects need to be estimated to isolate the warming effect of CO₂. Over time, the IPCC's estimate of the cooling effect of aerosols has declined (Lewis 2022).

Paleoclimate proxies are also used to evaluate the sensitivity of past climates, by comparing paleoclimate changes in the Earth's temperatures to estimates of changes in forcings. The two most informative periods are the last glacial maximum (around 20,000 years ago), which was about 3–7°C colder than today, and a mid-Pliocene period (roughly three million years ago), which was 1–3°C warmer than today. ~~source 4.1~~ The limits on cooling during the last glacial maximum give the best single evidence that high values of climate sensitivity are unlikely. However, paleoclimate estimates are associated with very large uncertainties in the estimated temperatures and forcings. Further, estimates of climate sensitivity based on past climate states may not be representative of the current state of the climate system.

A recurring theme in the climate literature is that ECS estimates based on historical data are smaller than ECS estimates inferred from climate models (Sherwood and Forest 2024). About 15 estimates based on historical data appeared in the peer-reviewed literature between 2012 and 2024 yielding ECS best estimates between 1.0°C and 2.5°C, although critics have questioned some of the methods and the data quality. For the AR6, the IPCC placed primary weight on the results of Sherwood et al. (2020) that combined historical and paleoclimate proxies and yielded a best estimate of 3.1°C. Lewis (2022) raised a number of concerns about this result, including methodological errors, outdated input values, and use of subjective versus objective Bayesian priors in the analysis. Lewis' analysis found that climate sensitivity is estimated to be much lower and better constrained than in the Sherwood et al. analysis – median 2.2°C (1.8–2.7°C in the 17–83 percent *likely* range, and 1.6–3.2°C in the 5–95 percent *very likely* range). ~~Lewis' analysis implies that climate sensitivity is considerably more likely to be below 2°C than above 2.5°C.~~ The IPCC AR6 estimated only a 5 percent probability that ECS was below 2.3°C, whereas Lewis estimated it to be over 50 percent. The most recent publications on the debate between Sherwood et al. and Lewis further defend their respective positions: Sherwood and Foster (2024) and Lewis (2025).

An interesting footnote is that in 1983, the US National Research Council conducted a follow-up study to the 1979 Charney Report and referring to the estimated sensitivity range of 1.5°C to 4.5°C said:

"The climate record of the past hundred years and our estimates of CO₂ changes over that period suggest that values in the lower half of this range are more probable."
Nierenberger et al. (1983, p. 2)

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Lewis' analysis likewise implies that climate sensitivity is likely in the lower half of the original 1979 Charney range.

An recent argument emphasized in , which the IPCC AR6 emphasized, is that data-driven ECS estimates might understate the future warming response to GHGs based because of on a so-called "pattern effect" (Forster et al 2021). The tropical Pacific is believed to be highly influential on to strongly influence the overall efficiency with which the Earth's climate radiates heat to space, but in some regions remove heat is more efficiently removed from the climate system than from others. If the west-to-east temperature gradient in the tropical Pacific is weakened in in a warming climate, there is a weakening of the west-to-east temperature gradient in the tropical Pacific, the result would be a concentration of warming would concentration in a region where heat is less efficiently removed, raising the ECS.

of the Earth's climate system. Most climate models simulate that rising GHGs will weaken the east-west temperature gradient, which led the IPCC in the AR6 to conclude that data-driven ECS estimates understated the future ECS value.

However, Seager et al. (2019) pointed out that, contrary to models, the east-west temperature gradient has been strengthening rather than weakening over time. They further argued that the mechanism predicting otherwise in climate models was based on a faulty characterization of oceanic dynamics and there is no reason to expect the gradient to weaken. A similar argument was recently made by Lee et al. (2024), who concluded that "the trajectory of the observed trend reflects the response to increasing GHG loading in the atmosphere"; in other words, GHG warming should lead to a future strengthening rather than a weakening of the temperature gradient. Increased efficiency of atmospheric cooling implies, if anything, that the future ECS in a warming climate may be *lower* than current estimates.

5.5 Transient Climate Response

The Transient Climate Response (TCR) is of greater utility in providing as provides a more useful observational constraint on climate sensitivity. TCR is the amount of warming that results when CO₂ is increased that would occur at the time when CO₂ doubles, having increased gradually at an annual rate of by 1 percent each year over a period of 70 years (i.e., doubled gradually). Relative to the ECS, observationally-determined values of TCR avoid the problems of uncertainties in ocean heat uptake and the fuzzy boundary in defining equilibrium arising from a range of timescales for the longer-term feedback processes (e.g., ice sheets). TCR is more generally related to peak warming and better constrained by historical warming, than ECS. The IPCC AR6 judged the very likely range of TCR to be 1.2–2.4°C. ^[source 47] In contrast to ECS, the upper bound of the TCR is more tightly constrained. For comparison, the TCR values determined by Lewis (2023) is are 1.25 to 2.0°C, -showing much better agreement with the AR6 values than was seen in a comparison of the ECS values.

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A related but more flexible parameter is the Transient Response to cumulative carbon Emissions, or TCRE, which relates global temperature change to the cumulative emissions. TCRE is based upon a linear relationship between global average temperature and cumulative emissions, which holds for cumulative emissions of up to 2-teratons 2,000 Gt of carbon (i.e. about two centuries at current rates).

For a given value of TCRE, we can estimate the ~~estimated~~ amount of warming expected over a future period in response to scenarios of cumulative carbon emission. The IPCC AR6 provides a *very likely* range for TCRE of 1.0–2.3°C, with a median value of 1.6°C.⁴⁸]

Commented [SK4]: Suggest remove this paragraph unless we're either going to use TCRE elsewhere in the report OR we're comparing different methods of estimating TCRE.

As will be discussed in Chapter 6, a real-world ECS below the model average is supported by studies which ~~that~~ show climate models on average estimate too much warming at the ~~overestimate the~~ observed surface and ~~and in the troposphere warming compared to observations over the past 50 years.~~ Lower sensitivities. Also, lower values also align with evidence from consistent fingerprinting (Section 2.8), where ~~that~~ model responses to GHGs need to be scaled down/downscaled quite a bit to align with observed trends.

5.6 Summary

In the past 5 years, there is a growing realization that climate models are not fit for the purpose of determining the sensitivity of the climate to increasing CO₂ (ECS), owing to the dependence of this sensitivity on poorly resolved processes related to clouds and water vapor.

Data-driven approaches using historical data and paleoclimate reconstructions are now regarded as more reliable for determining ECS, but their reliability is diminished by data inadequacies. The IPCC AR6 upper bound for the *likely* range of ECS is 4.0°C, lower than the AR5 value of 4.5°C. This lowering of the upper bound seems well justified by the paleoclimatic estimates of the ECS. The IPCC AR6 lower bound for the *likely* range of ECS is 2.5°C, substantially higher than the AR5 value of 1.5°C. This raising of the lower bound of the likely range of ECS has received a substantial challenge from the analysis of Lewis (2022, 2025) that finds the lower bound of the likely range to be 1.75°C with a median value of 2.21°C. Other lines of evidence supporting a lower bound on the ECS range below the IPCC AR6 value are discussed in Chapters 6 and 7.

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~~Estimates of the transient climate response (TCR, TCR6) are more tightly constrained on the upper bound than the ECS.~~

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5 Measuring Climate Sensitivity to CO₂ Forcing

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5.1 Introduction5.1 Model-based methods of computing climate sensitivity to GHGs

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The magnitude of the sensitivity of Earth's climate to increasing concentrations of CO₂ is at the heart of the scientific debate on anthropogenic climate change, and also the public debate on the appropriate policy response to increasing CO₂ in the atmosphere. Equilibrium Climate Sensitivity (ECS) refers to the expected amount of warming averaged over the Earth's surface in response to a doubling of CO₂, after all climate systems have had time to adjust. Some systems, like temperatures in the troposphere, adjust very rapidly. Others may take decades or even centuries, such as the deep ocean and the cryosphere. A related metric which is sometimes more helpful for analysis on shorter time scales is the Transient Climate Response (TCR) defined as the amount of warming after 70 years in which atmospheric CO₂ goes up by one percent annually.

In 1979 the Charney (1979) Report for the US National Academy of Sciences proposed that the most likely value for ECS was 3.0°C plus or minus 1.5°C. With only minor variations this range was adopted and reaffirmed by the IPCC until the most recent AR6. The ECS range between 1.5 and 4.5°C is characterized by the IPCC AR5 as the *likely* range (66 percent probability); the AR5 stated that ECS is *extremely unlikely* (95 percent probability) to be below 1.0°C and very unlikely (90 percent probability) to exceed 6.5°C. This range of ECS values has remained stubbornly wide, despite many individual studies claiming to narrow it. Most recently, the IPCC AR6 narrowed its assessment of the *likely* range of ECS to 2.5–4.0°C and the *very likely* range to be between 2.0 and 5.0°C. This narrowing of the range on the low end is disputed, as will be discussed below.

Although ECS is of intrinsic scientific interest it is also of central importance to evaluating the public danger posed by GHG emissions. Uncertainties about ECS are highly consequential for policy making. As will be discussed in Section Chapter 13, economic models take the ECS value from climate science and use it to project the costs of CO₂ emissions. The traditional ECS value (3.0 °C) has typically yielded modest global social costs of CO₂ emissions, enough to justify some policy actions though mostly deferred to later in the century. If ECS is very high (4.5°C or above) aggressive immediate emission controls become more imperative, whereas values closer to 2.0°C have been shown to be compatible with social costs of emissions being zero or even negative over the coming decades imply that no CO₂ emission controls are economically justifiable (Dayaratna et al. 2016, 2020). Obtaining a precise ECS estimate is therefore important for policy guidance. Obtaining a precise estimate is impossible, policy making needs to account for the uncertainty.

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In large-scale General Circulation Models (GCMs, aka climate models) ECS is not imposed as a direct parameter, instead it emerges from the behaviour of the underlying components of the model. These, however, are under the control of the modeler, so ultimately a model's ECS can be said to be built into it. Direct warming from CO₂ doubling is only about 1°C (Hall and Manabe 1997); the rest, to the extent more happens, arises due to climate feedbacks which are inherently more difficult to predict and model.

In 1979 the Charney (1979) Report for the US National Academy of Sciences proposed that the most likely value for ECS was 3.0°C plus or minus 1.5°C. Hence the best estimate was a likely tripling of the CO₂ effect through feedbacks. With only minor variations this range was adopted and reaffirmed by the IPCC until the most recent AR6.

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5.1.2 Model-based methods of computing climate sensitivity to GHGs

The ECS range has been obtained primarily by examining the behaviour of climate models, but since key components of models are under the control of modelers this is not dispositive of the actual climate's sensitivity.

There are approximately three dozen computer climate models operated by research groups around the world (Cannon 2024). GCMs are valuable tools for understanding the climate system from a theoretical perspective. But the models have become so complex, often with 1 million or more lines of computer code (Brown-Steiner 2024), that it would be prohibitively expensive and time consuming for anyone to replicate the models' projections of climate change, let alone test the myriad model approximations embedded in the computer codes; a climate model typically takes hundreds of experts many years to develop (McSweeney and Hausfather 2018). As a result these models are published in the scientific literature with little to no independent evaluation (Pirtle et al 2010). Climate modeling thus stands as an unusual class of scientific endeavor wherein researchers validating the scientific claims of others — a hallmark of science (National Academy of Science 2019) — becomes impractical, if not impossible.

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"We have documented how we tuned the MPI-ESM1.2 global climate model to match the instrumental record of warming; an endeavor which has clearly been successful. Due to the historical order of events, the choice was to do this practically by targeting an ECS of about 3 K using cloud feedbacks, [emphasis added] as opposed to tuning the aerosol forcing."

In other words, the modelers chose an ECS value of 3°C and then tuned the cloud parameterizations to match their intended result.

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Direct warming from CO₂ doubling is only about 1°C (Hall and Manabe 1997); the rest to the extent ~~more happens, arises due~~ higher values arise to from climate feedbacks that are not explicitly resolved by the model but rely on parameterizations of physical processes, ~~which are inherently more difficult to predict and model~~. Higher values of ECS arise primarily from positive cloud feedbacks. The magnitude, and even the sign, of cloud feedbacks is the greatest source of uncertainty. Elements of cloud feedback include changes in the latitudinal distribution of clouds, changes in the distribution of cloud height (changes in low versus high clouds), changes to the phase of clouds (ice versus liquid), changes in cloud particle size (associated with changes in concentration and/or composition of aerosol particles), changes in the precipitation efficiency of clouds, and even changes in how clouds are distributed over the daily solar cycle [source 35]. It is difficult for climate models to simulate any of these cloud processes correctly owing to their small scale, let alone predict how they will change in the future. Further, cloud processes modulate the magnitudes of the water vapor, lapse rate, and the surface albedo feedbacks [source 36].

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ECS can be determined from climate model simulations by doubling the concentration of CO₂, allowing several centuries for the warming to equilibrate. To avoid the necessity of long simulations, "effective climate sensitivity" is commonly evaluated from a 150-year simulation in response to a

sudden quadrupling of CO₂. The spread of ECS values from the CMIP5 climate models (used in the AR5) was 2.0–4.7°C; the spread has increased for the CMIP6 models (used in the AR6) to between 1.8 and 5.7°C [sources 37,38]. Far from the science being settled in relation to the response of the climate system to increasing greenhouse gas concentrations, insofar as it is represented by climate models, uncertainties appear to be growing. The main cause of the overall upward shift in ECS in CMIP6 relative to CMIP5 is a larger positive cloud feedback, driven by changes to the cloud parameterizations in many CMIP6 models [source 39].

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While the models are often touted as being accurate representations of the “basic physics” governing the climate system, they still have problems with model “drift,” in which the models slowly change temperature over centuries for no apparent reason (Grandey et al. 2023). The tendency to drift is adjusted for by climate modelers imposing the arbitrary assumption that Earth's climate system does not produce long-term climate change, unless caused by humans (Sen-Gupta et al. 2013). By suppressing all slow-moving warming and cooling in this way this biases model-based research away from potential natural causes of climate change, since it implies there can be no warming trends except in response to external forcing. In addition recent research suggests many models do not even conserve energy (Irving 2021)—a violation of the First Law of Thermodynamics. The First Law holds that energy can be neither created nor destroyed; to the extent that climate models fail to conserve energy, it can spontaneously appear (or disappear) for no apparent reason, causing a fictitious temperature change. This is a particularly important consideration since global warming theory is first and foremost based upon tiny changes in the global energy balance assuming the First Law holds.

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Because of concerns about model tuning and the high sensitivity to cloud parameterizations, the IPCC AR6 (2021) did not rely on climate model simulations in their assessment of climate sensitivity, relying on other methods in its assessment instead, chiefly a recent empirical estimate.

For all these reasons it should come as no surprise that the various models' responses to a hypothetical doubling of atmospheric CO₂ above pre-industrial levels produces a very wide range of ECS values in current models, from 1.83°C to 5.64°C in the IPCC AR6. This wide range of responses—the largest in over 30 years of the global climate modeling enterprise—demonstrates large remaining uncertainties in climate modeling and thus in the projection of global climate impacts imputed to human activities. It also implies that ECS cannot be determined from climate models alone since the range is too wide to be informative. For that reason scientists have increasingly turned to empirical methods.

4.5.2.3 Empirical Data-driven methods of computing climate sensitivity to GHGs

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Climate sensitivity can also be estimated from instrumental records of surface temperatures and ocean heat content, combined with estimates of how climate forcings (e.g., greenhouse gases, solar, volcanoes, aerosols) have changed in the past [source 40]. Using this information, a simple empirical model called an Energy Balance Model can be estimated. It requires estimating a feedback parameter which appears in the denominator of the resulting equation for ECS. NO EQUATIONS. whose uncertainties are highly amplified in the resulting ECS (Roe and Baker, 2007). A small amount of uncertainty about the number in the denominator of a fraction can lead to very large uncertainties in the magnitude of the fraction itself. Roe and Baker (2007) pointed out that for this reason uncertainties in climate feedbacks are "highly amplified" in the resulting ECS.

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Paleoclimate proxies are also used to evaluate the sensitivity of past climates by comparing paleoclimate changes in the Earth's temperatures to estimates of changes in forcings. The two most informative periods are the last glacial maximum (around 20,000 years ago), which was about 3–7°C colder than today, and a mid-Pliocene period (roughly three million years ago), which was 1–3°C warmer than today [source 41]. The limits on cooling during the last glacial maximum give the best single evidence that high values of climate sensitivity are unlikely. However, paleoclimate estimates are associated with very large uncertainties in the estimated temperatures and forcings. Further, estimates of climate sensitivity based on past climate states may not be representative of the current state of the climate system.

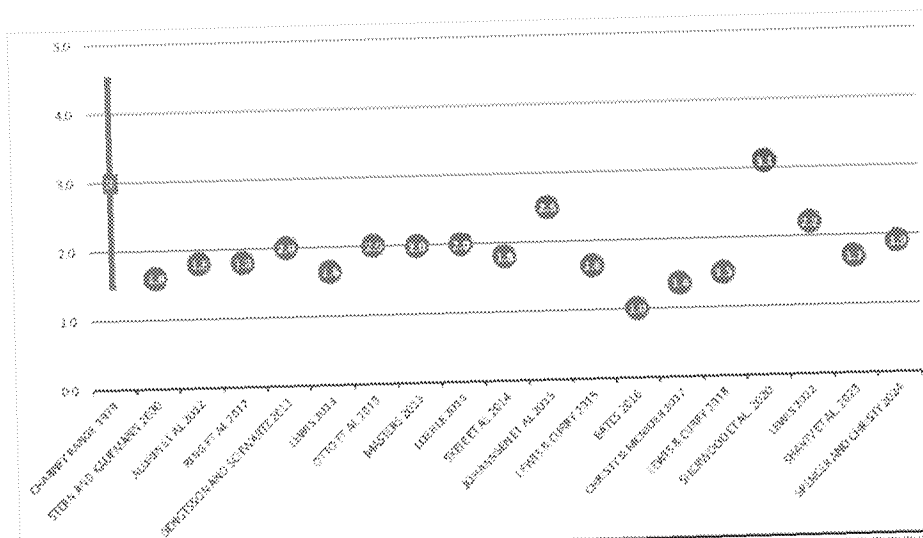
A significant amount of effort since the EF has gone into estimating ECS empirically. There are several challenges to this work:

- First, it requires good data but observations of some key climatic systems, especially the oceans, are available in only very limited amounts.
- Second, identifying the effect of CO₂ requires simultaneously identifying the effect of aerosols. Climate models exhibit warming in response to GHGs but cooling in response to aerosols (Schwartz et al. 2007). Observed 20th century warming can be shown to be consistent either with low ECS and low aerosol cooling or high ECS and high aerosol cooling. Since fossil fuel use adds both GHGs and aerosols to the atmosphere, both effects need to be estimated to isolate the warming effect of CO₂. Over time, the IPCC's estimate of the cooling effect of aerosols has declined (Lewis 2022).
- Third, the simple empirical model typically used for the estimation, called an Energy Balance Model, requires estimating a feedback parameter which appears in the denominator of the equation for ECS. A small amount of uncertainty about the number in the denominator of a fraction can lead to very large uncertainties in the magnitude of the fraction itself. Roe and Baker (2007) pointed out that uncertainties in climate feedbacks are "highly amplified" in the resulting ECS.

Since 2012 many studies have appeared in the literature tackling these various uncertainties. A recurring theme in the climate literature is that ECS estimates based on historical data turn out to be smaller than ECS estimates inferred from encoded in climate models (Sherwood and Forest 2024). An early empirical estimate (Stern and Kaufmann 2000) was 1.6°C, though this predated development of the Energy Balance Model method. Figure 4.25.1 shows the point or best estimates from 17 subsequent studies all appearing in the peer-reviewed literature after the TSD since 2012. The Charney range is shown for contrast. The average ECS point estimate in the post-2012 sample is 1.8°C. The highest estimate, from Sherwood et al. (2020), is shown in red: it is the one that was used highlighted by the IPCC for the AR6 and used to guide their assessment of the ECS range (Forster et al. 2021). The one adjacent to it, Lewis (2022), was published subsequent to the AR6 and presented an extensive critique of Sherwood et al. (2020).

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shows the result of, among other things, using the same statistical method (Bayesian inference) but applying more updated aerosol forcing data in the AR6 as well as some other recent updates to the source data. These updates dropped the ECS best estimate to 2.2°C, closer to the usual empirical range. The IPCC, following Sherwood et al. (2020) had estimated only a 5 percent probability that ECS was below 2.3°C, whereas Lewis (2022) estimated it was over 50 percent.



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Figure 4.25.1: Empirical best estimates of ECS. Vertical axis: °C.

[Judy I reinserted this Figure as I think it is an important visual indicator that Lewis 2022 is not a one-off outlier.]

I don't think this is needed. Lewis (2022) is not a historical empirical method, but rather uses the same approach as Sherwood et al. and AR6 in combining historical, paleo and feedback approaches. I don't think that the older ones are useful because the data is pretty old, and methods outdated. Lewis (2022) is clearly within the the AR5 range. I don't think we need to resurrect the old stuff.

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Key concerns raised by Lewis include methodological errors, outdated input values, and use of subjective versus objective Bayesian priors in the analysis. Lewis' analysis found that climate sensitivity is estimated to be much lower and better constrained than in the Sherwood et al. analysis – median 2.16°C (1.75–2.7°C in the 17–83 percent likely range), and 1.55–3.2°C in the 5–95 percent very likely range. Lewis' analysis implies that climate sensitivity is considerably more likely to be below 2°C than above 2.5°C. The IPCC AR6 estimated only a 5 percent probability that ECS was below 2.3°C, whereas Lewis (2022) estimated it to be over 50 percent. The most recent publications on the debate between Sherwood et al. and Lewis further defend their respective positions: Sherwood and Foster (2024) and Lewis (2025).

A recent hypothesis argument, which the IPCC AR6 emphasized, is that empirical data-driven ECS estimates might understate the future warming response to GHGs due to based on a so-called “pattern effect” (Forster et al 2021). The tropical Pacific is believed to be highly influential on the overall efficiency with which the Earth's climate radiates heat to space, but heat in some parts regions heat is more efficiently removed from the climate system than from others. If in a warming climate there is a weakening of the west-to-east temperature gradient in the tropical Pacific the result would be a concentration of warming in a region where heat is less efficiently removed, raising the ECS of the Earth's climate system. Most climate models simulate that rising GHGs will weaken the east-west temperature gradient, which led the IPCC in the AR6 to conclude that empirical data-driven ECS estimates understated what would be the future observed ECS value.

However, Seager et al. (2019) pointed out that, contrary to models, the east-west temperature gradient has been strengthening rather than weakening over time. They further argued that the mechanism predicting otherwise in climate models was based on a faulty characterization of oceanic dynamics and there is no reason to expect the gradient to weaken. A similar argument was recently made by Lee et al. (2024), who concluded that “the trajectory of the observed trend reflects the response to increasing GHG loading in the atmosphere”, in other words GHG warming should lead to a future strengthening rather than a weakening of the temperature gradient. Increased efficiency of atmospheric cooling implies, if anything, that the future ECS in a warming climate may be lower than at present current estimates.

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5.5 Transient Climate Response

The Transient Climate Response (TCR) is of greater utility in providing an observational constraint on climate sensitivity. TCR is the amount of warming that would occur at the time when CO₂ doubles, having increased gradually by 1 percent each year over a period of 70 years. Relative to the ECS, observationally-determined values of TCR avoid the problems of uncertainties in ocean heat uptake and the fuzzy boundary in defining equilibrium arising from a range of timescales for the longer-term feedback processes (e.g., ice sheets). TCR is more generally related to peak warming and better constrained by historical warming than ECS. The IPCC AR6 judged the very likely range of TCR to be 1.2–2.4°C [source 47]. In contrast to ECS, the upper bound of the TCR is more tightly constrained. For comparison, the TCR values determined by Lewis (2023) is 1.25 to 2.0°C, showing much better agreement with the AR6 values than was seen in a comparison of the ECS values.

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A related but more flexible parameter is the Transient Response to cumulative carbon Emissions, or TCRE, which relates global temperature change to the cumulative emissions. TCRE is based upon a linear relationship between global average temperature and cumulative emissions, which holds for cumulative emissions of up to 2 teratons of carbon. For a given value of TCRE, we can calculate the estimated amount of warming expected over a future period in response to scenarios of cumulative carbon emission. The IPCC AR6 provides a very likely range for TCRE of 1.0–2.3°C, with a median value of 1.6°C.48

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As will be discussed in ~~Section~~ Chapter 65 a real-world ECS below the model average is supported by studies which show climate models on average estimate too much warming at the surface and in the troposphere compared to observations over the past 50 years. Also it aligns with evidence from consistent fingerprinting (Section 67) that model responses to GHGs need to be scaled down quite a bit to align with observed trends.

5.6 Summary

In the past 5 years, there is a growing realization that climate models are not fit for the purpose of determining the sensitivity of the climate to increasing CO₂ (ECS), owing to the dependence of this sensitivity on poorly resolved processes related to clouds and water vapor.

Data-driven approaches using historical data and paleoclimate reconstructions are now regarded as more reliable for determining ECS, but their reliability is diminished by data inadequacies. The IPCC AR6 upper bound for the *likely* range of ECS is 4.0°C, lower than the AR5 value of 4.5°C. This lowering of the upper bound seems well justified by the paleoclimatic estimates of the ECS. The IPCC AR6 lower bound for the *likely* range of ECS is 2.5°C, substantially higher than the AR5 value of 1.5°C. This raising of the lower bound of the likely range of ECS has received a substantial challenge from the analysis of Lewis (2022, 2025) that finds the lower bound of the likely range to be 1.75°C with a median value of 2.16°C. Other lines of evidence supporting a lower bound on the ECS range below the IPCC AR6 value are discussed in Chapters 6 and 7.

Estimates of the transient climate response (TCR, TCRE) are more tightly constrained on the upper bound than the ECS.

[Indy I took out the assessed value statement since I don't think we need to generate one and I wouldn't know how to do it] **AGREED**

Mauritsen, T., & Roeckner, E. (2020). Tuning the MPI-ESM1.2 global climate model to improve the match with instrumental record warming by lowering its climate sensitivity. *Journal of Advances in Modeling Earth Systems*, 12, e2019MS002037. [HYPERLINK "<https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2019MS002037>"]

Zelinka, M. D., Myers, T. A., McCoy, D. T., Po-Chedley, S., Caldwell, P. M., Cepni, P., et al. (2020). Causes of higher climate sensitivity in CMIP6 models. *Geophysical Research Letters*, 47, e2019GL085782. [HYPERLINK "<https://doi.org/10.1029/2019GL085782>"]

In summary:

- ECS cannot be determined from climate modeling alone since models are too complex and uncertain to narrow the range
- Climate models on average embed process assumptions that yield a projected warming of about 3.0°C from CO₂. Empirical estimates since the TSD however imply the climate is much less sensitive to CO₂ than this.
- A large number of empirical ECS estimates have been centered at or below 2°C. This aligns with other independent forms of empirical evidence pointing towards low ECS.

5 Measuring Climate Sensitivity to CO₂ Forcing

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5.1 Introduction5.1 Model-based methods of computing climate sensitivity to GHGs

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The magnitude of the sensitivity of Earth's climate to increasing concentrations of CO₂ is at the heart of the scientific debate on anthropogenic climate change, and also the public debate on the appropriate policy response to increasing CO₂ in the atmosphere. Equilibrium Climate Sensitivity (ECS) refers to is defined as the expected amount of warming averaged over the Earth's surface in response to a doubling of CO₂, after all climate systems have had time to adjust. Some systems, like temperatures in the troposphere, adjust very rapidly. Others may take decades or even centuries, such as the deep ocean and the cryosphere. A related metric which is sometimes more helpful for analysis on shorter time scales is the Transient Climate Response (TCR) defined as the amount of warming after 70 years in which atmospheric CO₂ goes up by one percent annually.

In 1979 the Charney (1979) Report for the US National Academy of Sciences proposed that the most likely value for ECS was 3.0°C plus or minus 1.5°C. With only minor variations this range was adopted and reaffirmed by the IPCC until the most recent AR6. The ECS range between 1.5 and 4.5°C is characterized by the IPCC AR5 as the *likely* range (66 percent probability); the AR5 stated that ECS is *extremely unlikely* (95 percent probability) to be below 1.0°C and very unlikely (90 percent probability) to exceed 6.5°C. This range of ECS values has remained stubbornly wide, despite many individual studies claiming to narrow it. Most recently, the IPCC AR6 narrowed its assessment of the *likely* range of ECS to 2.5–4.0°C and the *very likely* range to be between 2.0 and 5.0°C. This narrowing of the range on the low end is disputed, as will be discussed below.

Although ECS is of intrinsic scientific interest it is also of central importance to evaluating the public danger posed by GHG emissions. Uncertainties about ECS are highly consequential for policy making. As will be discussed in Section Chapter 13, economic models take the ECS value from climate science and use it to project the costs of CO₂ emissions. The traditional ECS value (3.0 °C) has typically yielded modest global social costs of CO₂ emissions, enough to justify some policy actions though mostly deferred to later in the century. If ECS is very high (4.5°C or above) aggressive immediate emission controls become more imperative, whereas values closer to 2.0°C have been shown to be compatible with social costs of emissions being zero or even negative over the coming decades imply that no CO₂ emission controls are economically justifiable (Dayaratna et al. 2016, 2020). Obtaining a precise ECS estimate is therefore important for policy guidance.

In large-scale General Circulation Models (GCMs, aka climate models) ECS is not imposed as a direct parameter, instead it emerges from the behaviour of the underlying components of the model. These, however, are under the control of the modeler, so ultimately a model's ECS can be said to be built into it. Direct warming from CO₂ doubling is only about 1°C (Hall and Manabe 1997); the rest, to the extent more happens, arises due to climate feedbacks which are inherently more difficult to predict and model.

In 1979 the Charney (1979) Report for the US National Academy of Sciences proposed that the most likely value for ECS was 3.0°C plus or minus 1.5°C. Hence the best estimate was a likely tripling of the CO₂ effect through feedbacks. With only minor variations this range was adopted and reaffirmed by the IPCC until the most recent AR6.

5.1.2 Model-based methods of computing climate sensitivity to GHGs

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The ECS range has been obtained primarily by examining the behaviour of climate models, but since key components of models are under the control of modelers this is not dispositive of the actual climate's sensitivity.

There are approximately three dozen computer climate models operated by research groups around the world (Cannon 2024). GCMs are valuable tools for understanding the climate system from a theoretical perspective. But the models have become so complex, often with 1 million or more lines of computer code (Brown-Steiner 2024), that it would be prohibitively expensive and time consuming for anyone to replicate the models' projections of climate change, let alone test the myriad model approximations embedded in the computer codes; a climate model typically takes hundreds of experts many years to develop (McSweeney and Hausfather 2018). As a result, these models are published in the scientific literature with little to no independent evaluation (Pirtle et al 2010). Climate modeling thus stands as an unusual class of scientific endeavor wherein researchers validating the scientific claims of others — a hallmark of science (National Academy of Science 2019) — becomes impractical, if not impossible.

In large-scale General Circulation Models (GCMs, aka climate models) ECS is not imposed as a direct parameter, instead it emerges from the behaviour of the underlying components of the model. Collections of parameterizations are often chosen to produce an expected value of climate sensitivity, particularly with regards to sub-grid-scale cloud processes. Otherwise plausible models and parameter selections have been discarded because of perceived conflict with this warming rate, or aversion to a model's climate sensitivity being outside an accepted range. For example, Mauritsen and Roeckner (2020) state the following regarding their Max Planck Institute climate model:

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"We have documented how we tuned the MPI-ESM1.2 global climate model to match the instrumental record of warming: an endeavor which has clearly been successful. Due to the historical order of events, the choice was to do this practically by *targeting an ECS of about 3 K using cloud feedbacks*, [emphasis added] as opposed to tuning the aerosol forcing."

In other words, the modelers chose an ECS value of 3°C and then tuned the cloud parameterizations to match their intended result.

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Direct warming from CO₂ doubling is only about 1°C (Hall and Manabe 1997); the rest, to the extent more happens, arises due to climate feedbacks which are inherently more difficult to predict and model. Higher values of ECS arise primarily from positive cloud feedbacks. The magnitude, and even the sign, of cloud feedbacks is the greatest source of uncertainty. Elements of cloud feedback include changes in the latitudinal distribution of clouds, changes in the distribution of cloud height (changes in low versus high clouds), changes to the phase of clouds (ice versus liquid), changes in cloud particle size (associated with changes in concentration and/or composition of aerosol particles), changes in the precipitation efficiency of clouds, and even changes in how clouds are distributed over the daily solar cycle [source 35]. It is difficult for climate models to simulate any of these cloud processes correctly owing to their small scale, let alone predict how they will change in the future. Further, cloud processes modulate the magnitudes of the water vapor, lapse rate, and the surface albedo feedbacks [source 36].

ECS can be determined from climate model simulations by doubling the concentration of CO₂, allowing several centuries for the warming to equilibrate. To avoid the necessity of long simulations, "effective climate sensitivity" is commonly evaluated from a 150-year simulation in response to a sudden quadrupling of CO₂. The spread of ECS values from the CMIP5 climate models (used in the AR5) was 2.0–4.7°C; the spread has increased for the CMIP6 models (used in the AR6) to between 1.8

and 5.7°C [sources 37,38]. Far from the science being settled in relation to the response of the climate system to increasing greenhouse gas concentrations, insofar as it is represented by climate models, uncertainties appear to be growing. The main cause of the overall upward shift in ECS in CMIP6 relative to CMIP5 is a larger positive cloud feedback, driven by changes to the cloud parameterizations in many CMIP6 models [source 39]

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For all these reasons it should come as no surprise that the various models' responses to a hypothetical doubling of atmospheric CO₂ above pre-industrial levels produces a very wide range of ECS values in current models, from 1.93°C to 5.64°C in the IPCC AR6. This wide range of responses — the largest in over 30 years of the global climate modeling enterprise — demonstrates large remaining uncertainties in climate modeling and thus in the projection of global climate impacts imputed to human activities. It also implies that ECS cannot be determined from climate models alone since the range is too wide to be informative. For that reason scientists have increasingly turned to empirical methods.

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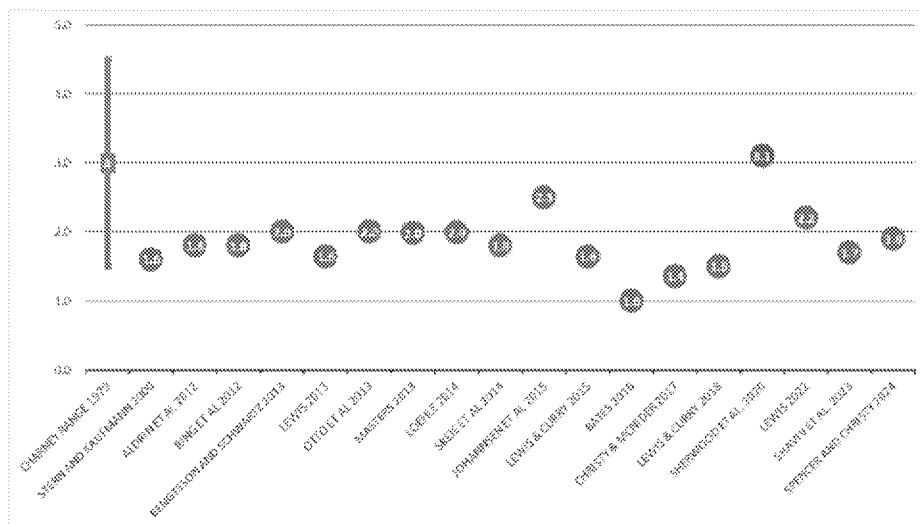


Figure 4.25.1: Empirical best estimates of ECS. Vertical axis: °C.

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Key concerns raised by Lewis include methodological errors, outdated input values, and use of subjective versus objective Bayesian priors in the analysis. Lewis' analysis found that climate sensitivity is estimated to be much lower and better constrained than in the Sherwood et al. analysis – median 2.16°C (1.75–2.7°C in the 17–83 percent likely range), and 1.55–3.2°C in the 5–95 percent very likely range. Lewis' analysis implies that climate sensitivity is considerably more likely to be below 2°C than above 2.5°C. The IPCC AR6 estimated only a 5 percent probability that ECS was below 2.3°C, whereas Lewis (2022) estimated it to be over 50 percent. The most recent publications on the

debate between Sherwood et al. and Lewis further defend their respective positions: Sherwood and Foster (2024) and Lewis (2025).

A recent hypothesis argument, which the IPCC AR6 emphasized, is that empirical data-driven ECS estimates might understate the future warming response to GHGs due to based on a so-called "pattern effect" (Forster et al 2021). The tropical Pacific is believed to be highly influential on the overall efficiency with which the Earth's climate radiates heat to space, but heat in some parts regions heat is more efficiently removed from the climate system than from others. If in a warming climate there is a weakening of the west-to-east temperature gradient in the tropical Pacific the result would be a concentration of warming in a region where heat is less efficiently removed, raising the ECS of the Earth's climate system. Most climate models simulate that rising GHGs will weaken the east-west temperature gradient, which led the IPCC in the AR6 to conclude that empirical data-driven ECS estimates understated what would be the future observed ECS value.

However Seager et al. (2019) pointed out that, contrary to models, the east-west temperature gradient has been strengthening rather than weakening over time. They further argued that the mechanism predicting otherwise in climate models was based on a faulty characterization of oceanic dynamics and there is no reason to expect the gradient to weaken. A similar argument was recently made by Lee et al. (2024), who concluded that "the trajectory of the observed trend reflects the response to increasing GHG loading in the atmosphere", in other words GHG warming should lead to a future strengthening rather than a weakening of the temperature gradient. Increased efficiency of atmospheric cooling implies, if anything, that the future ECS in a warming climate may be lower than at present current estimates.

5.5 Transient Climate Response

The Transient Climate Response (TCR) is of greater utility in providing an observational constraint on climate sensitivity. TCR is the amount of warming that would occur at the time when CO₂ doubles, having increased gradually by 1 percent each year over a period of 70 years. Relative to the ECS, observationally-determined values of TCR avoid the problems of uncertainties in ocean heat uptake and the fuzzy boundary in defining equilibrium arising from a range of timescales for the longer-term feedback processes (e.g., ice sheets). TCR is more generally related to peak warming and better constrained by historical warming than ECS. The IPCC AR6 judged the *very likely* range of TCR to be 1.2–2.4°C. [source 47] In contrast to ECS, the upper bound of the TCR is more tightly constrained. For comparison, the TCR values determined by Lewis (2023) is 1.25 to 2.0°C, showing much better agreement with the AR6 values than was seen in a comparison of the ECS values.

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A related but more flexible parameter is the Transient Response to cumulative carbon Emissions, or TCRE, which relates global temperature change to the cumulative emissions. TCRE is based upon a linear relationship between global average temperature and cumulative emissions, which holds for cumulative emissions of up to 2 teratons of carbon. For a given value of TCRE, we can calculate the estimated amount of warming expected over a future period in response to scenarios of cumulative carbon emission. The IPCC AR6 provides a *very likely* range for TCRE of 1.0–2.3°C, with a median value of 1.6°C.48

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As will be discussed in Section-Chapter 65 a real-world ECS below the model average is supported by studies which show climate models on average estimate too much warming at the surface and in the troposphere compared to observations over the past 50 years. Also it aligns with evidence from consistent fingerprinting (Section 67) that model responses to GHGs need to be scaled down quite a bit to align with observed trends.

5.6 Summary

In the past 5 years, there is a growing realization that climate models are not fit for the purpose of determining the sensitivity of the climate to increasing CO₂ (ECS), owing to the dependence of this sensitivity on poorly resolved processes related to clouds and water vapor.

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Data-driven approaches using historical data and paleoclimate reconstructions are now regarded as more reliable for determining ECS, but their reliability is diminished by data inadequacies. The IPCC AR6 upper bound for the *likely* range of ECS is 4.0°C, lower than the AR5 value of 4.5°C. This lowering of the upper bound seems well justified by the paleoclimatic estimates of the ECS. The IPCC AR6 lower bound for the *likely* range of ECS is 2.5°C, substantially higher than the AR5 value of 1.5°C. This raising of the lower bound of the likely range of ECS has received a substantial challenge from the analysis of Lewis (2022, 2025) that finds the lower bound of the likely range to be 1.75°C with a median value of 2.16°C. Other lines of evidence supporting a lower bound on the ECS range below the IPCC AR6 value are discussed in Chapters 6 and 7.

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Estimates of the transient climate response (TCR; TCRE) are more tightly constrained on the upper bound than the ECS.

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Mauritsen, T., & Roeckner, E. (2020). Tuning the MPI-ESM1.2 global climate model to improve the match with instrumental record warming by lowering its climate sensitivity. *Journal of Advances in Modeling Earth Systems* 12, e2019MS002037. [HYPERLINK "https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2019MS002037"]

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Zelinka, M. D., Myers, T. A., McCoy, D. T., Po-Chedley, S., Caldwell, P. M., Cepi, P., et al. (2020). Causes of higher climate sensitivity in CMIP6 models. *Geophysical Research Letters* 47, e2019GL085782. [HYPERLINK "https://doi.org/10.1029/2019GL085782"]

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In summary:

- ECS cannot be determined from climate modeling alone since models are too complex and uncertain to narrow the range
- Climate models on average embed process assumptions that yield a projected warming of about 3.0°C from CO₂. Empirical estimates since the TSD however imply the climate is much less sensitive to CO₂ than this.
- A large number of empirical ECS estimates have been centered at or below 2°C. This aligns with other independent forms of empirical evidence pointing towards low ECS.

12 Mortality risks from heat and cold temperature extremes

Changes in temperature extremes are among the most certain impacts expected in a warming globe -- extreme heat events are expected to become more frequent while extreme cold events become less frequent. This pattern The greatest confidence for impacts from global warming is an increase in extreme heat events and a decrease in extreme cold events; this has been observed is evident in the historical period (as discussed in Section XX) and is also expected to intensify with continued warming.

Mortality from during heat extremes is typically caused by heat stroke and heat exhaustion, while mortality from during cold extremes is typically caused by hypothermia and heart strain. It is well known that global mortality is substantially greater for extreme cold than for extreme heat.^{1,2}

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Specifically with regards to the U.S., extreme heat and extreme cold both kill hundreds of people each year; however, different approaches to assessing heat/cold mortality produces different results. The Center for Disease Control (CDC) National Center for Health Statistics Compressed Mortality Database, which is based on death certificates, indicates that about twice as many people die of "excessive cold" conditions in a given year than of "excessive heat."^{3,4}

A 2015 epidemiological study of deaths published in *The Lancet* found that cold-related deaths in the U.S. were about a factor of fifteen higher than heat-related deaths.⁵ However, the study did not adjust for the seasonal cycle in mortality rates, which tend to increase during the winter months due to non-weather factors like influenza.⁶ A more recent paper found that 86% of temperature-related deaths in the U.S. are due to cold-related mortality.⁷

¹ Qi Zhao et al., "Global, Regional, and National Burden of Mortality Associated with Non-Optimal Ambient Temperatures from 2000 to 2019: A Three-Stage Modelling Study," *The Lancet Planetary Health* 5, no. 7 (July 2021), [https://doi.org/10.1016/s2542-5196\(21\)00081-4](https://doi.org/10.1016/s2542-5196(21)00081-4).

² <https://ourworldindata.org/part-one-how-many-people-die-from-extreme-temperatures-and-how-could-this-change-in-the-future>

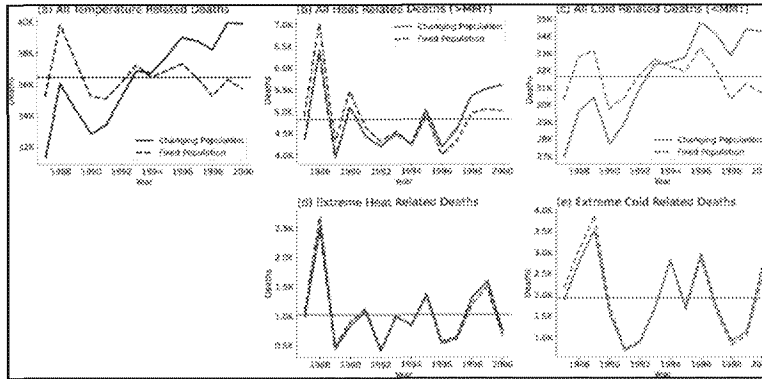
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⁵ Lancet Commission on Climate and Health, "Health and Climate Change: Policy Responses to Protect Public Health," *The Lancet* 386, no. 10006 (November 7, 2015): 1861-1914, [https://doi.org/10.1016/S0140-6736\(15\)60854-6](https://doi.org/10.1016/S0140-6736(15)60854-6).

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⁷ Taik Benmahnia et al., "Deaths Attributable to Heat and Cold: Comparison of Data Sources and Evaluation of Inconsistencies," *GeoHealth* 8, no. 3 (March 2024): e2023GH000799, <https://doi.org/10.1029/2023GH000799>.



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Figure 12.1: Time series of temperature-related deaths across all 106 cities. (a) The solid line represents total temperature-related deaths, while the dashed line indicates temperature-related deaths with a fixed population (average population from the 1987–2000 period). (b) Similar to (a), but for heat-related deaths. (c) Similar to (a), but for cold-related deaths. (d) Time series of deaths occurring in temperatures above the 97.5th percentile. (e) Similar to (d), but for temperatures below the 2.5th percentile. From <https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2023GH000799>

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The IPCC AR6 Working Group 2 Chapter 16.2.3.5 states how heat-related mortality is declining over time:⁸

“Heat-attributable mortality fractions have declined over time in most countries owing to general improvements in health care systems, increasing prevalence of residential air conditioning, and behavioral changes. These factors, which determine the susceptibility of the population to heat, have predominated over the influence of temperature change.”

A 2011 study of 40 major US cities between 1975 and 2004, found that heat wave mortality had decreased, in spite of rising temperatures, due to adaptation.⁹

By reducing mortality from cold events and adapting to heat extremes, rising temperatures are associated with a net saving of lives.

It is both disappointing and telling to see how the IPCC misrepresents the situation in its AR6 Synthesis report. Section A.2.5 of that document states: “In all regions increases in extreme heat

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⁹ Keith T. Ingram, Carolyn W. Fuman, and John W. Jones, “Climate Change Impact and Adaptation Assessment: A Guide for Coastal Resources Managers,” *Weather, Climate, and Society* 3, no. 4 (October 2011): 234–249, <https://doi.org/10.1175/WCAS-D-11-00055.1>.

events have resulted in human mortality and morbidity (*very high confidence*).” But it is silent on the larger decline of deaths during extreme cold events.

Mortality risks and energy costs

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A 2016 study of US long term mortality risks associated with temperature variations (Barreca et al. 2016) showed that increases in mortality across the US are associated both with cold weather and hot weather. But over time, the introduction of electricity and the adoption of central heating and air conditioning (AC) dramatically reduced both risks, especially those associated with hot weather. Prior to 1960, a day above 90°F (32°C) added 2.2 percent to the average mortality risk rate, but after 1960 the same weather added only 0.3 percent to mortality risk, an 85 percent reduction. Prior to 1960 temperatures below 39°F (4°C) added about 1 percent to mortality risk but after 1960 the same weather only added about half that amount. Adaptation through conventional household improvements dramatically reduced public vulnerability to weather extremes. The entire reduction in hot weather mortality was attributable to widespread adoption of indoor AC, which depended on the availability of reliable and affordable electricity.

The corollary of this finding is that the use of heating and cooling systems depends on energy being affordable. Doremus et al. (2022) showed that wealthy and poor households in the US adjust their energy expenditures at similar rates in response to moderate temperature swings, but not in response to extreme temperature swings. When temperatures swing to very cold levels (< 5°C) energy spending in high-income households rises by 1.2 percent but in low-income households by only 0.5 percent. On very hot days (>30°C) electricity spending in high-income households rises by 0.5 percent but does not change at all in low-income households. The latter result is observed even in subsamples where all households have AC. The implication is that even with widespread adoption of home heating and cooling systems, inability to afford energy leaves low-income households exposed to weather extremes.

Barreca, Alan, Karen Clay, Olivier Deschenes, Michael Greenstone, and Joseph S. Shapiro, “Adapting to climate change: The remarkable decline in the US temperature mortality relationship over the twentieth century,” *Journal of Political Economy*, 2016, 124 (1), 105–159.

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J.M. Doremus, I. Jacqz and S. Johnston (2022), “Sweating the energy bill: Extreme weather, poor households, and the energy spending gap,” *Journal of Environmental Economics and Management*, doi: [HYPERLINK “https://doi.org/10.1016/j.jeem.2022.102609”]_.

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Specifically with regards to the U.S., extreme heat and extreme cold both kill hundreds of people each year; however, different approaches to assessing heat/cold mortality produces different results. The Center for Disease Control (CDC) National Center for Health Statistics Compressed Mortality Database, which is based on death certificates, indicates that about twice as many people die of "excessive cold" conditions in a given year than of "excessive heat."^{3,4}

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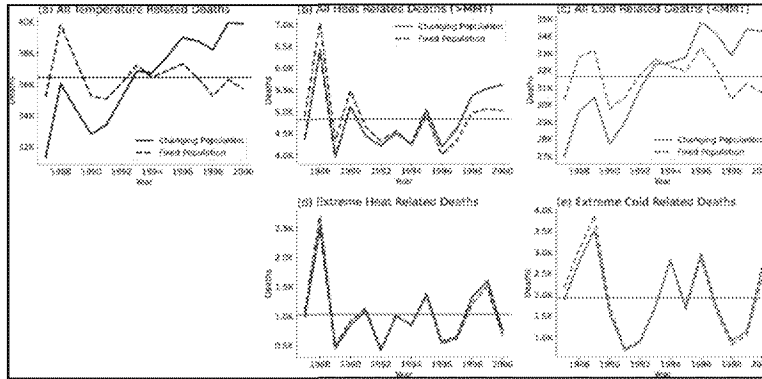
³ Bert R. Scheffers et al., "The Broad Footprint of Climate Change from Genes to Biomes to People," *Science* 354, no. 6313 (November 11, 2016): aaf7671, <https://doi.org/10.1126/science.aaf7671>.

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⁵ Lancet Commission on Climate and Health, "Health and Climate Change: Policy Responses to Protect Public Health," *The Lancet* 386, no. 10006 (November 7, 2015): 1861-1914, [https://doi.org/10.1016/S0140-6736\(15\)60854-6](https://doi.org/10.1016/S0140-6736(15)60854-6).

⁶ Bob Henson, "Which Kills More People: Extreme Heat or Extreme Cold?" *Weather Underground*, January 22, 2019, <https://www.wunderground.com/cat6/Which-Kills-More-People-Extreme-Heat-or-Extreme-Cold>.

⁷ Taik Benmahnia et al., "Deaths Attributable to Heat and Cold: Comparison of Data Sources and Evaluation of Inconsistencies," *GeoHealth* 8, no. 3 (March 2024): e2023GH000799, <https://doi.org/10.1029/2023GH000799>.



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By reducing mortality from cold events and adapting to heat extremes, rising temperatures are associated with a net saving of lives.

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events have resulted in human mortality and morbidity (*very high confidence*).” But it is silent on the larger decline of deaths during extreme cold events.

10. Climate change and US agriculture

10.1 Evidence based Econometric analyses on land values

Scientists have long known about the beneficial effect of CO₂ on plant growth and have studied it extensively. Thousands of experiments in laboratories and outdoor field settings (CO2Science.org, undated) have confirmed beneficial effects for food plants and crops of all kinds from higher CO₂ levels.

Econometric analyses of the effects of climate change on agriculture have sought to integrate information about long term crop yield changes in response to temperature and precipitation changes under assumptions about adaptive behavior by farmers. One method focuses on variations in agricultural land values. The rationale is that if climate change is a long-term net benefit for agriculture it should translate into higher market values for agricultural land, and vice versa. While individual crops might benefit from or be harmed by climate change, once the adaptive responses of farmers are taken into account the value of farmland represents an index of whether the changes are expected to be beneficial or not. Evidence that CO₂-induced warming will be neutral or beneficial for agriculture, particularly in the US, goes back decades. Mendelsohn et al. (1994) examined the effects—relationship between of historical climatic variations on agricultural land values and concluded “our projections suggest that global warming may would be slightly beneficial to American agriculture.” Mendelsohn et al. (2000) provided a global assessment of the impacts of 2°C warming by 2060, (which would be equivalent to 3.3 °C warming per century). They concluded that 2°C warming “will result in net market benefits for most OECD countries”. Tol (2002) published estimates of the global impact on agriculture of a 2.5 degree C warming. Assuming farmers adapt to the changes, he expected every region to end up better off.

The Mendelsohn et al. method, called Ricardian analysis after David Ricardo, the 19th century British economist who pioneered the study of land values, attracted subsequent criticism from authors who argued it failed to account for differences in land values attributable to fixed locational characteristics like soil quality, and non-climatic changes including nearby urbanization. Deschênes and Greenstone (2007) looked at agricultural profits instead of land values and reached similar conclusions to Mendelsohn et al. (1994), namely that past climatic variations had relatively little effect on farm profitability and that warming would likely yield small overall benefits for the US agricultural sector. However a subsequent exchange with critics led them (Deschênes and Greenstone 2012) to revise their conclusions and project potentially large losses in US agriculture due to climate warming. Burke and Emerick (2016) looked at temperature variations over 1980 to 2000 and argued that farmers were not as able to adapt to temperature changes as the Ricardian method assumes and that climate change would have large negative impacts on corn and soy yields. Schlenker and Roberts (2009) similarly argued that yield gains to past warming would not carry over to the future and corn and soy yields would sharply decrease this century due to climate change.

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~~DEFINE LAND VALUE ARE YOU JUST TALKING ABOUT AGRICULTURE OR SOMETHING ELSE~~ Two recent studies have argued that pessimistic findings such as these are not robust. Ortiz-Bobea (2019) argued that land values aggregate farm and non-farm influences and the latter need to be filtered out. He developed a data set using cash rents for agricultural activity as a measure of land value specifically for farming activity. Whereas the land value model implied future losses under climate warming, the same model estimated using cash rents did not, leading the author to conclude the pessimistic results were due to using an inaccurate measure of the returns to farming activity. Bareille and Chakir (2023) assembled a large data base on farm sale prices in France for properties that sold twice between 1996 and 2019. They could replicate pessimistic results showing negative effects of warming on agricultural land values using conventional econometric modeling. But by

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taking advantage of the repeat sales data, which provides information on site-specific changes in land prices, they found the results reversed and implied that climate change will be very beneficial for French agriculture. The authors concluded that, taking adaptation into account, a warming climate would yield positive benefits for French agriculture that were between two and 20 times larger than had previously been estimated. On average, with full adaptation, they concluded that climate changes under the medium RCP4.5 scenario could double the value of French farmland by 2100. There have been criticisms of the methodology used by Mendelsohn et al. (1994) to associate land value changes with climate change. It was later criticized by others for potentially leaving out other important determinants of land value that change over time SUCH AS WHAT, leading some authors to argue that the benefits of warming would be much smaller or even negative. Bareille and Chakir (2023) addressed the criticisms by assembling a large data base on farm sale prices in France for properties that sold twice between 1996 and 2019. By comparing the change in land value on the same farm to local climatic and economic changes they were able to remove the confounding influence of fixed site-specific characteristics and isolate the contribution of climate variables. These authors concluded that, taking adaptation into account, a warming climate would yield positive benefits for French agriculture that were between two and 20 times larger than had previously been estimated. On average, with full adaptation, climate changes anticipated under the medium RCP4.5 scenario could add 100% to double the value of French farmland by 2100. They also noted that application of earlier methods to the same data would suggest climate change would be harmful to harm French agriculture.

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A major deficiency of all these studies, however, is that they omit the role of CO₂ fertilization. Climate change as it relates to this report is caused by GHG emissions, chiefly CO₂. The econometric analyses referenced above focus only on temperature and precipitation changes and do not take account of the beneficial growth effect of the additional CO₂ that drives them. As explained in Chapter 2 CO₂ is a major driver of plant growth so this omission biases the analysis towards underestimation of the benefits of climate change on agriculture. THE PREVIOUS PARAGRAPHS ARE CONFUSING. I WOULD JUST TALK ABOUT AGRICULTURE AND NOT LAND VALUE, UNLESS YOU DEFINE NON-AG VALUES

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10.2 Field studies of CO₂ enrichment

As discussed in Chapter 2, I PREFER TO SEE THIS MATERIAL IN CHAPTER 10 RATHER THAN IN CHAPTER 2, scientists have used so-called Free Air CO₂ Enrichment, or FACE, experiments to measure how well plants in outdoor settings responds in outdoor settings to local increases in the level concentration of carbon dioxide. One of the ways the effect of CO₂ on crop growth has been studied is through "free air enrichment experiment" or FACE plots, in which small chimneys are placed in fields surrounding plants and the growth response to elevated CO₂ under varying weather conditions are recorded. Ainsworth et al. (2020) summarizes results from about 250 such studies. They found that elevation of CO₂ by 200 ppm cause an average 18% increase in crop yield in C3 plants. C4 plants exhibited benefits mainly under drought conditions. In For instance in a 2021 study that reviewed 160 FACE experiments conducted over 20 years, Hu et al. (2021) concluded that elevated CO₂ levels had boosted rice growth on average by 16 percent. Furthermore, when they looked at hybrid varieties especially particularly suited to the higher CO₂ levels, the growth increased by was nearly 25 percent.

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In addition to FACE plot experiments there have been thousands of laboratory experiments on the effects of CO₂ on all kinds of plant growth. Here we review some of the results on key US agricultural crops.

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Soybean

Studies on the impact of elevated CO₂ on Soybean (*Glycine max* (L.) Merr.) plants in the water-deficient region of Huang-Huai-Hai Plain, China, showed that elevated CO₂ concentrations resulted in improved photosynthesis rate, water use efficiency and growth (Li, 2013) under both normal conditions and drought conditions. The CO2Science.org website reports on 108 published experiments between 1985 and 2019 exposing soybean to enriched CO₂ levels. Converted to a +300ppm common scale the average growth benefit was +50.9 percent. In addition there were 10 studies reporting on +600 ppm CO₂ enrichment, resulting in an average increase in photosynthesis of 90.3%.

Maize (corn)

The CO2Science.org website reports on 28 published experiments between 1983 and 2018 exposing corn (*Zea mays* L.) to enriched CO₂ levels. Converted to a +300ppm common scale the average growth benefit was +23.7 percent. Corn also benefits from increased drought tolerance under elevated CO₂. An experimental study (Allen Jr, 2011) exposed plants to water stress conditions in sunlit controlled-environment chambers at 360 ppm (ambient) and 720 ppm (elevated) CO₂. The drought stress caused a 41% loss of growth under ambient CO₂ but only a 13% loss under elevated CO₂.

Wheat

The CO2Science.org website reports on 92 published experiments between 1983 and 2020 exposing common wheat (*Triticum aestivum* L.) to enriched CO₂ levels. Converted to a +300ppm common scale the average growth benefit was +67.6 percent. Blandino (2020) measured the yield as well as nutritional quality of an "improver" hybrid wheat variety and its parents under elevated CO₂ levels (+166 ppm). They reported a grain yield increase of +16% but a 7% decrease in grain protein levels. But they found that the food quality of different wheat varieties responded differently to elevated CO₂ levels, so that with proper varietal selection end-users can select wheat types that best take advantage of the elevated CO₂.

Further evidence

Wheat also benefits from CO₂-induced climate change. The website CO2Science.org {[HYPERLINK "http://www.co2science.org/data/plant_growth/photo/t/triticuma.php"](http://www.co2science.org/data/plant_growth/photo/t/triticuma.php)} reports on 92 published experiments between 1983 and 2020 exposing wheat to enriched CO₂ levels. Converted to a +300 parts per million common scale, the average growth boost was 67.6 percent.

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A 2021 report from the US National Bureau of Economic Research (Taylor and Schlenker 2021) used satellite-measured observations of outdoor CO₂ levels across the United States, matched to county-level agricultural output data and other economic variables. After controlling for the effects of weather, pollution and technology the authors concluded that ~~since 1940~~ CO₂ emissions had boosted US crop production ~~since 1940~~ by 50 to 80 percent, ~~attributing much larger attributable gains than~~ had previously been estimated using FACE experiments. They found that every ~~1-part-per-million~~ of increase in CO₂ levels ~~concentration~~ boosts corn yields by 0.5 percent, soybeans by 0.6 percent, and wheat by 0.8 percent.

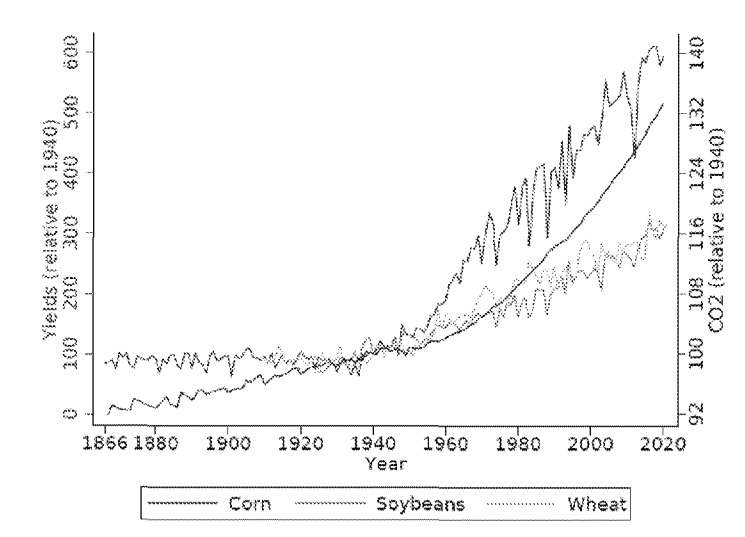


Figure 10.1: US average CO₂ levels and yields of corn, soy and wheat all normalized so 1940=100.
Source: Taylor and Schlenker (2021)

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In addition to Beyond growth benefits, extra CO₂ boosts plant resilience to heat. Derying et al. (2016) surveyed all available evidence regarding how wheat, maize, rice and soybean will grow under a combination of climate warming and rising CO₂ levels. DUPPLICATIVE OF CH 2, I PREFER THIS MATERIAL IN CH 10 They concluded that warming would, eventually, have a negative effect on plant growth but it would be fully compensated for by the extra CO₂ for wheat and soybean, and almost completely fully for rice and maize. Also And as discussed in Chapter 2, the plants use water more efficiently when become far more efficient in their water usage when there is more CO₂ in the air.

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Derying et al. (2016) surveyed evidence on crop water productivity (CWP), i.e. yield per unit of water used, drawing attention to the potential for CO₂ both to enhance photosynthesis and reduce leaf-level transpiration (water loss during leaf respiration). They surveyed all available FACE data on crop yield changes for Maize (corn), Wheat, Rice and Soybean, and combined it with crop model data simulating yield responses as of 2080 under the extreme RCP8.5 scenario in four growing regions (Tropics, Arid, Temperate and Cold) each of which were split into rainfed and irrigated sub-regions. In every region they reported that models without CO₂ fertilization predicted CWP losses but CO₂ fertilization more than offset them and once it was taken into account all regions showed a net CWP gain. Deryng et al (2016) also reported that negative impacts on wheat and soybean yields were fully offset by CWP gains, and mitigated by up to 90% for rice and 60% for maize.

Similar to this, Cheng et al. (2017) noted that increased global plant growth from 1982 to 2011 due to rising CO₂ uptake was accompanied by such large gains in CWP that despite the extra biomass global water use by plants had not increased.

Deryn et al. (2016) assumed that climate change would “exacerbate water scarcity”. It is noteworthy that while models predict drylands will expand under climate warming, current data show the opposite: greening is happening even in arid areas. Zhang et al. (2014) report that due to increased CO₂ levels “increasing aridity in drylands won’t lead to a general loss of vegetation productivity”, increased desertification will happen in at most 4% of currently arid areas.

Adaption plays a key role in exploiting gains from climate change for US crops. Butler et al. (2018) examined US maize production since 1981 and found that weather changes had been a net benefit. They also found that “current farmer cropping schedules are more beneficial in the climate of the last decade than they would have been in earlier decades” and adaptive responses to warming had added 13 kg per hectare to maize production. They estimated that weather trends since 1981 had raised boosted US maize production by 28% since 1981.

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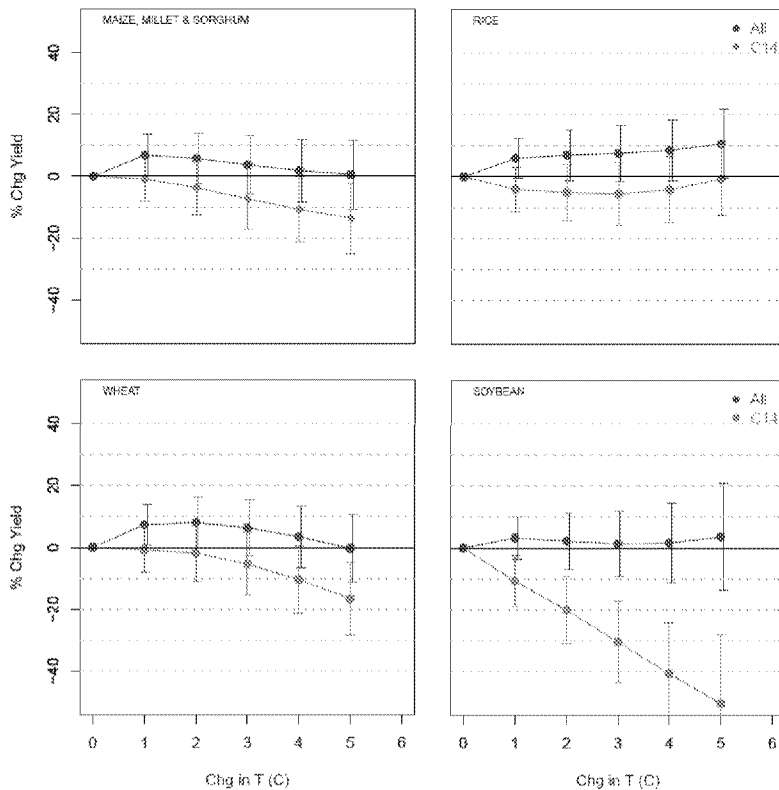


Figure 10.1-2 Crop yields under CO₂-induced climate warming. Blue: as published in Moore et al. (2017). Green: after including omitted data. Source: McKittrick (2025).

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Deschênes, Olivier and Michael Greenstone (2007) The Economic Impacts of Climate Change: Evidence from Agricultural Output and Random Fluctuations in Weather *American Economic Review* Feb 2007, Vol. 97, No. 1: Pages 354-385

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Deschênes, Olivier and Michael Greenstone (2012) The Economic Impacts of Climate Change: Evidence from Agricultural Output and Random Fluctuations in Weather: Reply to Comment
American Economic Review, 102, no. 7: 3761-3773. [HYPERLINK
"http://hdl.handle.net/1721.1/82641"]

Ortiz-Bobea, Ariel (2019) The role of nonfarm influences in ricardian estimates of climate change impacts on US agriculture.*American Journal of Agricultural Economics*, 102 (3), 934-959.

Schlenker, Wolfram and Michael Roberts (2009) Nonlinear temperature effects indicate severe damages to U.S. crop yields under climate change.*Proceedings of the National Academy of Sciences* 106 (37) 15594-15598 [HYPERLINK "https://doi.org/10.1073/pnas.0906865106"]

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10. Climate change and US agriculture

10.1 Ricardian analysis ~~CHANGE THE SECTION TITLE TO SOMETHING PEOPLE WILL UNDERSTAND WITHOUT DEFINING THE WORD RICARDIAN~~

Scientists have long known about the beneficial effect of CO₂ on plant growth and have studied it extensively. Thousands of experiments in laboratories and outdoor field settings (CO2Science.org, undated) have confirmed beneficial effects for food plants and crops of all kinds from higher CO₂ levels.

Evidence that CO₂-induced warming will be neutral or beneficial for agriculture, particularly in the US, goes back decades. Mendelsohn et al. (1994) examined the effects of historical climatic variations on agricultural land values and concluded "our projections suggest that global warming may be slightly beneficial to American agriculture." Mendelsohn et al. (2000) provided a global assessment of the impacts of 2°C warming by 2060, ~~(which would be equivalent to 3.3 °C warming per century)~~. They concluded that 2°C warming "will result in net market benefits for most OECD countries". Tol (2002) published estimates of the global impact on agriculture of a 2.5 degree C warming. Assuming farmers adapt to the changes, he expected every region to end up better off.

~~DEFINE LAND VALUE ARE YOU JUST TALKING ABOUT AGRICULTURE OR SOMETHING ELSE~~ There have been criticisms of ~~(The method methodology)~~ used by Mendelsohn et al. (1994) to associate land value changes with climate change, ~~it was later criticized by others for potentially leaving out~~ other important determinants of land value that change over time ~~SUCH AS WHAT~~, leading some authors to argue that the benefits of warming would be much smaller or even negative. Bareille and Chakir (2023) addressed the criticisms by assembling a large data base on farm sale prices in France for properties that sold twice between 1996 and 2019. By comparing the change in land value on the same farm to local climatic and economic changes they were able to remove the confounding influence of fixed site-specific characteristics and isolate the contribution of climate variables. ~~They~~ Those authors concluded that, taking adaptation into account, a warming climate would yield positive benefits for French agriculture that were between two and 20 times larger than had previously been estimated. On average, with full adaptation, climate changes anticipated under the medium RCP4.5 scenario could ~~add 100% to double~~ the value of French farmland by 2100. They also noted that application of earlier methods to the same data ~~would suggest~~ climate change would be ~~harmful to harm~~ French agriculture.

~~THE PREVIOUS PARAGRAPHS ARE CONFUSING. I WOULD JUST TALK ABOUT AGRICULTURE AND NOT LAND VALUE, UNLESS YOU DEFINE NON-AG VALUES~~

10.2 Field studies

As discussed in Chapter 2, ~~I PREFER TO SEE THIS MATERIAL IN CHAPTER 10 RATHER THAN IN CHAPTER 2~~, scientists have used so-called Free Air CO₂ Enrichment, or FACE, experiments to measure how ~~well plants in outdoor settings~~ responds ~~in outdoor settings~~ to local increases in the ~~level concentration~~ of carbon dioxide. ~~In~~ For instance, in a 2021 study that reviewed 160 FACE experiments conducted over 20 years, Hu *et al.* (2021) concluded that elevated CO₂ levels had boosted rice growth on average by 16 percent. Furthermore, when they looked at hybrid varieties ~~especially particularly~~ suited to the higher CO₂ levels, ~~the growth increased by~~ was nearly 25 percent.

Wheat also benefits from CO₂-induced climate change. The website CO2Science.org ([[HYPERLINK "http://www.co2science.org/data/plant_growth/photo/t/triticuma.php"](http://www.co2science.org/data/plant_growth/photo/t/triticuma.php)]) reports on 92 published experiments between 1983 and 2020 exposing wheat to enriched CO₂ levels. Converted to a +300 parts per million common scale, the average growth boost was 67.6 percent.

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A 2021 report from the US National Bureau of Economic Research (Taylor and Schlenker 2021) used satellite-measured observations of outdoor CO₂ levels across the United States, matched to county-level agricultural output data and other economic variables. After controlling for the effects of weather, pollution and technology the authors concluded that ~~since 1940~~ CO₂ emissions had boosted US crop production ~~since 1940~~ by 50 to 80 percent, ~~attributing~~ much larger ~~attributable~~ gains than had previously been estimated using FACE experiments. They found that every ~~1 part per million ppm~~ of increase in CO₂ levels ~~concentration~~ boosts corn yields by 0.5 percent, soybeans by 0.6 percent, and wheat by 0.8 percent.

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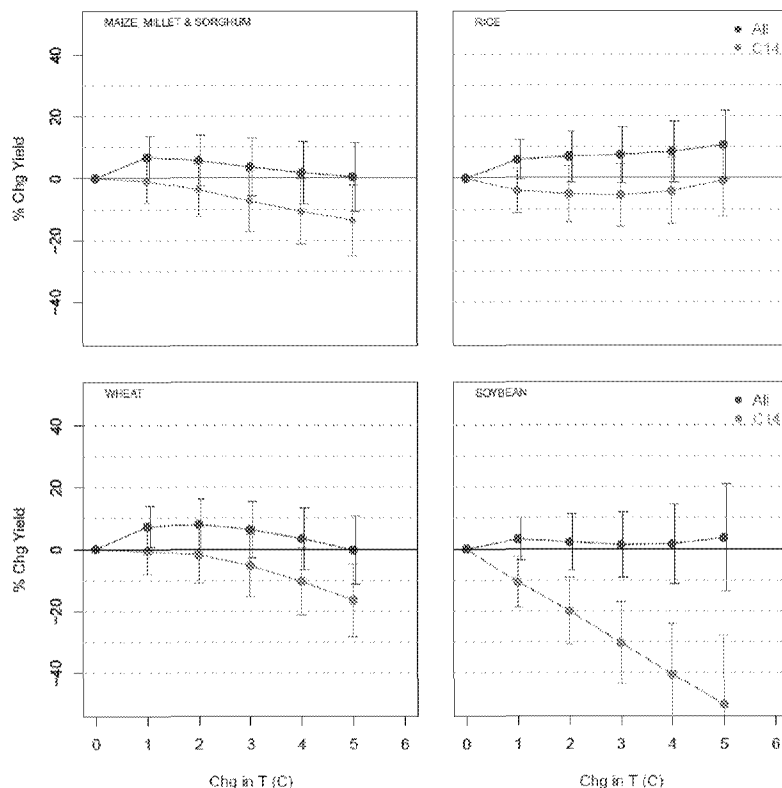


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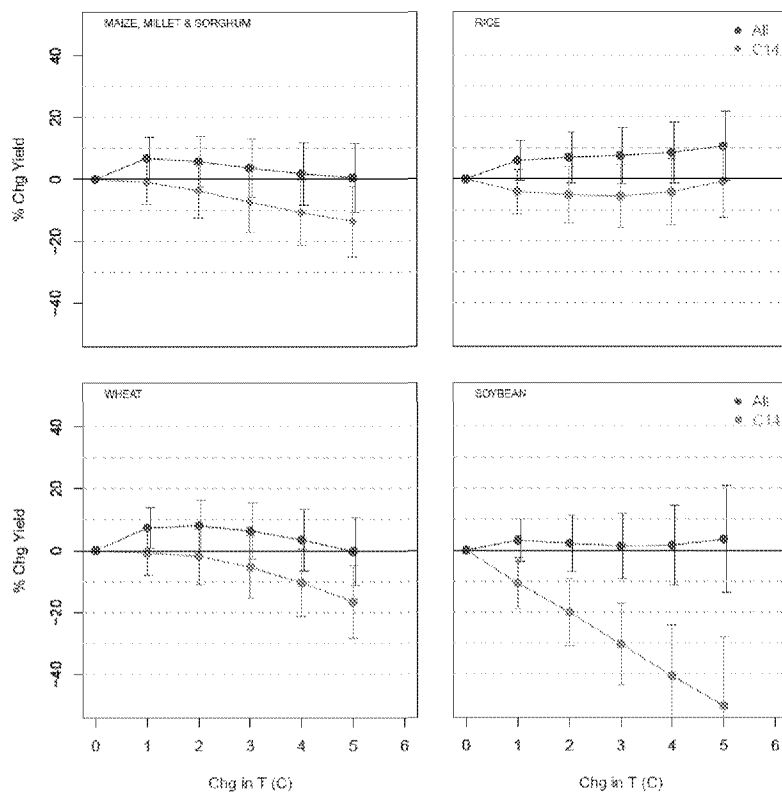


Figure 10.1 Crop yields under CO₂-induced climate warming. Blue: as published in Moore et al. (2017). Green: after including omitted data. Source: McKittrick (2025).

United States Department of Energy

Climate Science, Greenhouse Gases
and the Management of US Weather Risks

Report of the Climate Science Advisory Group
May 28, 2025

Climate Science, Greenhouse Gases
and the Management of US Weather Risks

Report of the Climate Science Advisory Group

John Christy, Ph.D.

Judith Curry, Ph.D.

Steven Koonin, Ph.D.

Ross McKittrick, Ph.D.

Roy Spencer, Ph.D.

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Foreword: Secretary Chris Wright

Foreword: CSAG

This document originated in late March 2025 when Secretary Wright assembled an independent team to write a report on issues in climate science relevant for energy policymaking, with particular focus on the question of whether carbon dioxide emissions endanger the US public. The team agreed to undertake the work on the condition that there would be no editorial oversight by the Secretary, the Department of Energy, or any other government personnel. This condition has been honored throughout the process and the writing team has worked with full independence.

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The team began working in early April with a deadline of May 28. The short timeline and the technical nature of the material meant that we could not comprehensively review all topics. While the report is intended to be accessible for non-experts, we have omitted some introductory or explanatory material that can easily be accessed elsewhere. Nor have we attempted to survey entire literatures related to the topics covered. The scientific and technical material herein only samples vast literature on climate change but is, we believe, more than sufficient to establish our conclusions.

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The team writing this report was not involved in, nor briefed on, any Administration plans or processes related to a potential challenge to the 2009 EPA CO₂ Endangerment Finding. We were asked, however, to include some information related to the role of US motor vehicles in global climate change, since that is an issue of relevance to the Department of Energy.

The writing team is grateful to Secretary Wright for the opportunity to prepare this report and for his support for independent scientific inquiry.

Part I: Direct Human Influence on Ecosystems and the Climate

1. Carbon dioxide as distinct from criteria air contaminants

This report is chiefly concerned with carbon dioxide (CO₂) emissions from fossil fuel use. Although it has become common to refer to CO₂ as “pollution” this is a misnomer. In the framework of United States clean air policy there are six types of so-called Criteria Air Contaminants (EPA, undated): particulate matter, ground-level ozone, Sulfur Dioxide, Nitrogen Dioxide, Lead and carbon monoxide (CO). Air contaminants are subject to regulatory control because they cause local problems depending on concentrations that include nuisances (odor, visibility problems), damage to plants and, at high enough exposure levels, toxicological effects in humans.

CO₂ has not historically been viewed as an air pollutant in the US or elsewhere because it is odorless, does not affect visibility and has no toxicological effects at ambient levels. It is a naturally-occurring part of the atmosphere and a key component of human and plant respiration. CO₂ is essential for plant photosynthesis and higher levels are generally considered beneficial for vegetation, as will be discussed in this report.

Ambient outdoor air contains about 420 parts per million (ppm) CO₂. The US Occupational Safety and Health Administration issues guidelines for indoor workplaces in which elevated CO₂ may be encountered, such as where dryice is used. The Permissible Exposure Limit is 5,000 ppm over 8 hours (OSHA 2024). Allen et al. (2015) reported evidence of diminished performance on some cognitive tasks among workers in office cubicles when exposed to CO₂ levels above 1,000-1,500 ppm.

The main concern about CO₂ is its potential effects on the global climate. This is a very complex question which will occupy much of this report. We will begin in the next section by looking at the role of CO₂ in promoting global greening and agricultural productivity growth, then we will examine the effect of CO₂ on ocean alkalinity. We then turn to CO₂'s role as a so-called greenhouse gas (GHG), beginning with a brief description of radiative forcing, the carbon cycle and the role of aerosols. Part II of this report discusses in detail the topic of the climatic response to GHGs. Part III discusses some aspects of the impacts of climate change on ecosystems and society.

US Environmental Protection Agency (Undated) Criteria Air Pollutants. [[HYPERLINK "https://www.epa.gov/criteria-air-pollutants"](https://www.epa.gov/criteria-air-pollutants)] accessed April 29 2025.

US Occupational Health and Safety Administration (2024) “OSHA Occupational Chemical Database: Carbon Dioxide” [[HYPERLINK "https://www.osha.gov/chemicaldata/183"](https://www.osha.gov/chemicaldata/183)]

Allen, Joseph G, Piers MacNaughton, Usha Satish, Suresh Santanam, Jose Vallarino and John D.S. Spengler (2015) Associations of Cognitive Function Scores with Carbon Dioxide, Ventilation, and Volatile Organic Compound Exposures in Office Workers: A Controlled

2. CO₂ fertilization and global greening

2.1. CO₂ and global greening

“Greening” refers to an increase in the total amount of the Earth’s surface covered in plants. The main measure of greening is “Leaf Area Index” or LAI as measured by satellite. Many studies over the past decade have confirmed a global greening pattern (rising LAI) attributable to rising CO₂ levels. Zhu et al. (2016) was one of the first studies to report that global greening was detectable from space using satellite sensors. On data spanning 1982 to 2011 they detected greening over 25-50% of the Earth versus browning over only 4%, and they attributed 70% of the greening to rising CO₂ levels (see Figure 2.3).

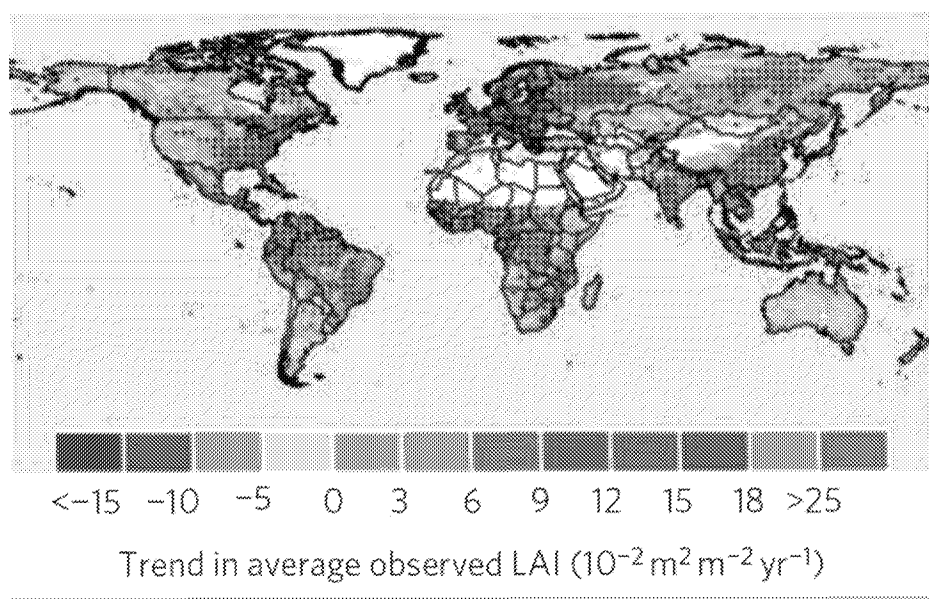


Figure 2.1.1: Trends in average Leaf Area Index (LAI). Source: Zhu et al. 2016 Figure 3.

Zheng (2017) confirmed the pattern, noting that greening over 30 years had added 8% to global leaf area and that greening was mitigating warming. Greening has been observed globally but Chen et al. (2019) noted that China and India were taking particular advantage of it though land management changes. Thus while China accounts for only 6.6% of global vegetated area it

accounts for 25% of global net increase in LAI. Rao et al. (2020) noted that greening was even observable in the Arctic.

[While plant models predict increases in photosynthesis should be observed in response to rising CO₂, Haverd et al. (2020) reported that observed CO₂ fertilization rate was nearly double what models had predicted. That is, CO₂ fertilization had driven an increase in observed global photosynthesis by 30% since 1900, versus 17% predicted by plant models. Among other things this indicates that global models of the socioeconomic impacts of climate change have likely understated the benefits to crops and agriculture from rising CO₂. The connection between CO₂ fertilization and climate policy will be discussed in Chapter XX.]

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Finally, Chen et al. surveyed claims that greening had slowed down since 2000 due to drought stress. They found instead that claims of slowed greening could be attributed to faulty satellite sensors. Once the data were corrected they found greening was accelerating over 55% of the world while browning was accelerating over only 7% of the world. Overall the greening trend was continuing with no evidence of slowdown, and CO₂ fertilization remained the dominant driver.

2.2. Photosynthesis and CO₂ levels

A key direct effect of adding CO₂ to the atmosphere is its positive effect on plant life via enhancement of photosynthesis and improvement to plant water use efficiency.

The term *photosynthesis* describes the process by which plants build biomass. The process requires carbon dioxide (CO₂), water (H₂O), and light. The plant enzyme responsible for photosynthesis is called Ribulose-1,5-bisphosphate-carboxylase/oxygenase or "Rubisco". Photosynthesis is initiated when CO₂ is available at the surface of the RuBisCo enzyme where it is converted to a molecule with 3 carbon atoms and thereafter incorporated into plant mass, which is referred to as the C3 process.

Rubisco is estimated to have evolved about 3 billion years ago. Over geological time the Earth's atmospheric CO₂ levels were usually much higher than they are today. About 400 million years ago CO₂ levels were an estimated 2,000-4,000 ppm and were at or above 1,000 ppm for much of the interval from 200 to 50 million years ago (Berner 2006, Judd et al. 2024). Over the past 35 million years the level of atmospheric CO₂ has been steadily declining. During glacial periods levels have fallen as low as 170 ppm (Gerhart and Ward 2010). In response to low-CO₂ conditions some plants evolved another photosynthetic pathway called C4, in which CO₂ is concentrated in the vicinity of Rubisco allowing for the C3 process to function more efficiently. For agricultural purposes the plant categories are:

- C3: rice, wheat, soybeans and most other crops
- C4: maize (corn), sugar cane, millet, sorghum

Had atmospheric CO₂ levels continued declining, plant growth rates would have declined and eventually ceased. Below 180 ppm many C3 species experience growth rate reductions on the order of 40-60% compared to their growth rates at 350 ppm (Gerhart and Ward 2010). C3 plants have been observed under experimental conditions to stop growing altogether at levels between 60—140 ppm CO₂. Some C4 plants are still able to grow at levels even as low as 10 ppm, albeit very slowly (Gerhart and Ward 2010).

Currently, CO₂ levels are about 420 ppm, up from 280 ppm in the early 1800s. The positive response of plants to extra CO₂ is illustrated in Figure 1 which is reproduced from Gerhart and Ward (2010). It shows the growth effect of CO₂ on Velvetleaf (*Abutilon theophrasti*) seedlings over 14 days under controlled conditions where only the CO₂ exposure is varied. The gains exhibited from increasing CO₂ from 150 ppm to 350 ppm continue under a further doubling to 700 ppm.

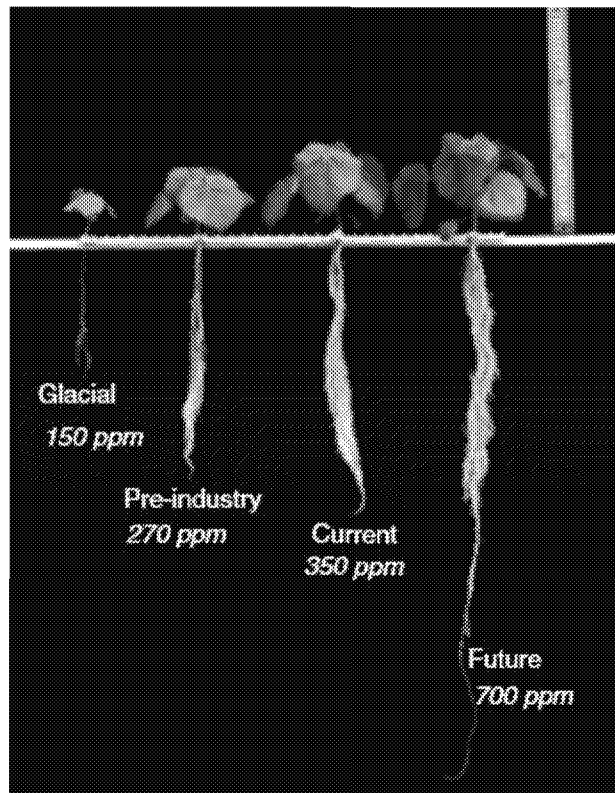


Figure 2.21: growth of *Abutilon theophrasti* after 14 days under identical conditions but for the indicated variations in CO₂ levels. Source: Gerhart and Ward (2010).

Over the past 60+ years there have been tens of thousands of studies on the response of plants to rising CO₂ levels. The overwhelming theme is that plants, especially C3 plants, benefit from extra CO₂. There are two mechanisms by which CO₂ confers a growth benefit:

- Enhanced photosynthesis via the metabolic pathways described above.
- Increased water use efficiency. This arises because plants draw in CO₂ by opening the stomata (pores) on the leaf surface. When CO₂ is scarce the stomata must be kept wide open for long periods, which allows water to evaporate away. Under enriched CO₂ conditions the stomata are closed for longer periods helping the plant retain water longer, thereby increasing water use efficiency.

Specific effects of climate change on US agriculture will be reviewed in Chapter XX.

2.3. Rising CO₂ and crop water use efficiency

Deryng et al. (2016) surveyed evidence on crop water productivity (CWP), i.e. yield per unit of water used, drawing attention to the potential for CO₂ both to enhance photosynthesis and reduce leaf-level transpiration (water loss during leaf respiration). They surveyed all available FACE data on crop yield changes for Maize (corn), Wheat, Rice and Soybean, and combined it with crop model data simulating yield responses as of 2080 under the extreme RCP8.5 scenario in four growing regions (Tropics, Arid, Temperate and Cdd) each of which were split into rainfed and irrigated sub-regions. In every region they reported that models without CO₂ fertilization predicted CWP losses but CO₂ fertilization more than offset them and once it was taken into account all regions showed a net CWP gain. Deryng et al. (2016) also reported that negative impacts of warming on wheat and soybean yields were fully offset by CWP gains, and mitigated by up to 90% for rice and 60% for maize.

Similar to this, Cheng et al. (2017) noted that increased global plant growth from 1982 to 2011 due to rising CO₂ uptake was accompanied by such large gains in CWP that despite the extra biomass global water use by plants had not increased.

Deryng et al. (2016) assumed that climate change would “exacerbate water scarcity”. It is noteworthy that while models predict drylands will expand under climate warming, current data show the opposite: greening is happening even in arid areas. Zhang et al. (2014) report that due to increased CO₂ levels “increasing aridity in drylands won’t lead to a general loss of vegetation productivity”; increased desertification will happen in at most 4% of currently arid areas.

2.4. Concealment of CO₂ fertilization benefits in IPCC Reports

If CO₂ emissions were discovered to be causing global crop declines and regional browning we would almost certainly have seen it discussed prominently in IPCC reports, and indeed it likely would have been the subject of its own chapter in an Assessment Report if not an IPCC Special Report. By contrast the IPCC has been almost silent on the topic of global greening.

The topic is briefly acknowledged in a few places in the body of the IPCC 6th and earlier Assessment Reports but is omitted in all Summary documents. Section 23.4.3.3 of the AR6 Working Group I report is titled “global greening and browning.” It points out that the IPCC Special Report on Climate Change and Land had concluded with high confidence that greening had increased globally over the past 2-3 decades. It then discusses the various estimate of greening trends, notes that there are variations in the estimates among data sets and then says that while they have *high confidence* greening has occurred, they have *low confidence* in the magnitude of the trend. There are also brief mentions of CO₂ fertilization effects and improvements in water use efficiency in a few other chapters in the AR6 Working Groups I and II Reports.

Overall, however, the Policymaker Summaries, Technical Summaries and Synthesis Reports are conspicuous for their failure to discuss the topic.

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3. Increasing CO₂ and the Alkaline Oceans

The modern-day global average pH of sea water is estimated to be 8.1, down from an estimated value of 8.2 in pre-Industrial times (Gattuso and Hansson, 2011). As CO₂ concentrations in the atmosphere increase, more is absorbed by the oceans. Depending upon the alkalinity (buffering capacity) of the oceans, the oceans are expected to become somewhat less alkaline over time, putatively explaining the decrease in pH from 8.2 to 8.1 over the last few hundred years.

While this process is often called “ocean acidification”, this is a misnomer because the oceans are not expected to become acidic (pH less than 7.0). Even if that was to happen, it is believed that life in the oceans evolved during a period when the oceans were mildly acidic, with a pH of 6.5 to 7.0 (Kriessansen-Totton et al, 2018).

For many years it was assumed that a decreasing pH of sea water would reduce the calcification rate of coral reefs. But coral reefs already endure large swings in pH, partly due to daily photosynthetic activity in the reef. This results in pH values that have been measured to range from 9.4 during the day to 7.5 at night (Revelle and Fairbridge, 1957).

In 2009 it was reported that a portion of Australia’s Great Barrier Reef (GBR, the world’s largest coral reef ecosystem) had experienced a 14% decline in calcification since 1990 (De’ath et al., 2009). This was tentatively attributed to increasing water temperature and decreasing pH of seawater. But since that time, the initial 2009 report of reduced calcification rates in the GBR was reported to have been the result of a bias in the data analysis (Ridd et al., 2013), and correction for this bias led to no change in calculated calcification rates. Nevertheless, the alarm produced by the original paper has persisted as evidenced by the large number of published citations (541) received by the original study as compared to only 11 citations for the subsequent study (as of 30 April 2025).

Given the reported declines in GBR coverage between 1990 and 2009, it has come as a surprise that the decline reversed over the last decade or so, with Woods Hole Oceanographic Institution asking, “Is the Great Barrier Reef Making a Comeback?” (Woods Hole, 2023). The most recent annual summary of GBR conditions from the Australian Institute of Marine Science was titled, Continued Coral Recovery Leads to 36-year Highs across Two-Thirds of the Great Barrier Reef (AIMS, 2022). Much of the decline in the GBR before 2011 turned out to be due to intense tropical cyclone activity (Beeden et al., 2015), and recovery of the reef from storm damage takes years.

On the time scale of thousands of years, boron isotope proxy measurements of pH show that ocean pH was around 7.4 or 7.5 during the last Ice Age (up to about 20,000 years ago) increasing to present-day values when the world warmed during deglaciation (Rae et al., 2018). Thus, there appears to be considerable resilience of ocean biota to natural long-term changes in ocean pH since marine organisms are exposed to wide ranges in pH anyway.

It is being increasingly recognized that publication bias (alarming ocean acidification results preferred by high-impact research publications) leads to exaggerated impacts from more alkaline oceans. An ICES Journal of Marine Science Special Issue addressed this problem with an article entitled, Towards a Broader Perspective on Ocean Acidification Research. In the Introduction to that Special Issue, H. I. Browman stated, “As is true across all of science, studies

that report no effect of ocean acidification are typically more difficult to publish.” (Browman, 2016)

Similarly, a meta-analysis of the negative effects of ocean acidification on reef fishes found that initially dramatic conclusions published in the scientific literature were all but refuted upon subsequent analysis involving larger sample sizes of data (Clements et al., 2021).

In conclusion, it is becoming increasingly apparent that the effect of ocean “acidification” on marine biota has likely been exaggerated.

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4. Human influences on the climate

4.1. Components of radiative forcing and their history

Historical radiative forcing

A changing climate has been the norm throughout the Earth's 4.6-billion-year history. The Earth's temperature and weather patterns change naturally over timescales ranging from decades to millions of years. Natural variations in the surface climate originate in two ways. Internal climate fluctuations associated with circulations in the atmosphere and ocean produce exchanges of energy, water, and carbon between the atmosphere, oceans, land, and ice. External influences on the climate system include variations in the energy received from the sun and the effects of volcanic eruptions. Human activities influence climate through changing land use and land cover. Humans are also changing the composition of the atmosphere by increasing emissions of CO₂ and other greenhouse gases and by altering the concentrations of aerosol particles in the atmosphere.

The earth is warmed by the sunlight it absorbs and cooled by the radiative heat it emits to outer space. Averaged over Earth, each of these processes involve power flows of about 240 Watts per square meter (W/m²). When they are in balance, there are no net external causes of warming or cooling. Human (and some natural) influences on the climate alter this balance and so cause the climate to change.

Influences on the energy balance are quantified by "radiative forcing", the extent to which they disturb the warming/cooling balance; a positive forcing warms while a negative forcing cools. The IPCC's estimated history of major components of radiative forcing since 1750 is shown in the following two figures from the IPCC AR6.

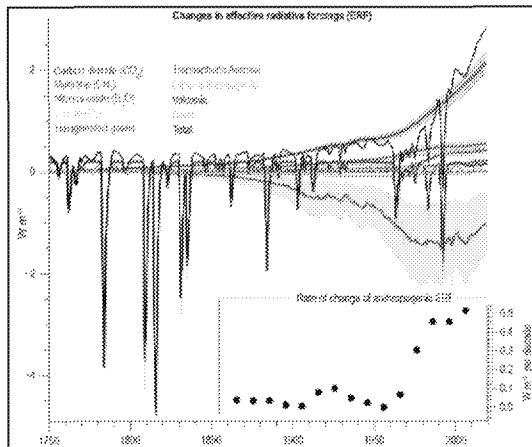


Figure 4.1.1: IPCC estimates of radiative forcing components over time. Source: [HYPERLINK "<https://www.ipcc.ch/report/ar6/wg1/figures/chapter-2/figure-2-10/>"]

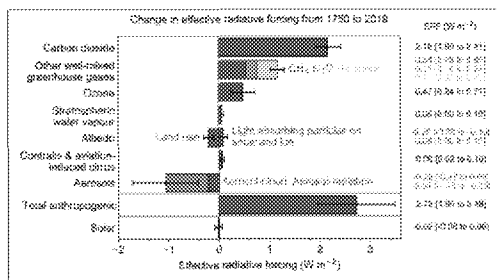


Figure 4.1.2 IPCC estimates of radiative forcing component changes from 1750 to 2019. Source: [[HYPERLINK "https://www.ipcc.ch/report/ar6/wg1/figures/chapter-7/figure-7-6/"](https://www.ipcc.ch/report/ar6/wg1/figures/chapter-7/figure-7-6/)]

These graphs show that the total radiative forcing is comprised of natural and anthropogenic components. Carbon dioxide is the largest human influence on the climate and the one most relevant to the effects of energy-using systems like motor vehicles. It exerts a warming influence by decreasing the cooling power of the atmosphere. Emissions of CO₂ are accumulating in the atmosphere, as described in the following section, so that the warming influence is increasing. Other greenhouse gases (methane, nitrous oxide, halogens, and ozone), which act similarly, currently add another 75% to CO₂'s warming. Aerosols exert a cooling effect, although with large uncertainties in the way they catalyze the formation of reflective clouds. As a result, understanding of the causes of recent warming requires not just identifying the warming effects of CO₂, but also the more uncertain cooling effects of sulfate aerosols.

The IPCC views the role of the sun as negligible, based on their preference for reconstructions that imply minimal solar change since preindustrial times. Connolly *et al.* (2021) reviewed sixteen different Total Solar Irradiance (TSI) reconstructions in the literature covering the 1600-2000 interval; they vary from almost no change in TSI to a relatively large upward trend. Connolly *et al.* point out that the variation in TSI reconstructions combined with variations in surface temperature reconstructions implies pairings can be found that are consistent with either no or most 20th century warming being attributable to the sun. A particularly thorny issue is the gap in the TSI data between 1989 and 1991 due to a delay in the launch of a monitor after the Space Shuttle Challenger disaster on January 28 1986, which prevented a replacement satellite from being launched in time to overlap with, and its readings to be intercalibrated with, the prior system (Zacharias 2014, Scafetta *et al.* 2019). The question of whether there is an upward trend in TSI over 1978 to 2018 comes down to how the missing data in that gap are filled.

The other natural forcing component is largely volcanic aerosols, which exert an episodic cooling influence.

The anthropogenic forcing component was negligible before about 1900 and has increased steadily since, rising to almost 3 W/m² today. However, this is still only about 1 percent of the unperturbed radiation flows, making it a challenge to isolate the effects of anthropogenic forcing since state-of-the-art satellite estimates of global radiative energy flows are only accurate to a

few Wm^2 . Natural sources of global energy imbalance other than volcanoes are not included in these graphs because they remain largely unknown.

Future radiative forcing

Carbon dioxide's warming influence depends upon how much "extra" CO_2 accumulates in the atmosphere- i.e., its concentration. The CO_2 level as recorded at the Mauna Loa observatory in Hawaii is generally used as the representative global average concentration. The data are available online at [HYPERLINK "<https://gml.noaa.gov/ccgg/trends/index.html>"]. The concentration was about 316 ppm at the start of the record in 1959 and is now about 425 ppm, a 34 percent increase.

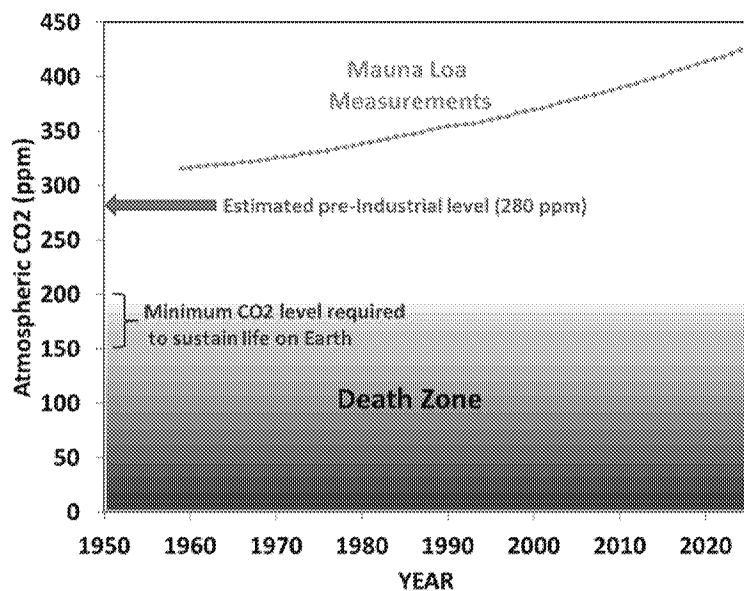


Fig. 4.1.3 Yearly average atmospheric CO_2 concentrations (1959-2024) measured at Mauna Loa, HI (green) compared to the estimated pre-Industrial CO_2 concentration of 280 ppm, and the estimated minimum levels required to sustain life on Earth (150 to 200 ppm). Need source

The annual increase in concentration is only about half of the CO_2 emitted because land and ocean processes absorb "excess" CO_2 at a rate approximately 50% of human emissions. Thus, future concentrations, and hence future human influences on the climate, depend upon two components: (1) future rates of global human CO_2 emissions, and (2) how fast the land and ocean remove extra CO_2 from the atmosphere. We discuss each of these in turn.

4.2. Future emission scenarios and the carbon cycle

Emission scenarios

Assessing the future dangers of GHG emissions requires assumptions about what those emissions will be. Future emissions, and hence human influences on the climate, will depend upon future demographics, economic progress, regulation, and the energy and agricultural technologies in use. Various assumptions about each of those lead to projections of greenhouse gas emissions and concentrations, aerosol concentrations, and changes in land use, which ultimately can be combined into assumptions about anthropogenic radiative forcing.

Because of the great uncertainties about these many factors in the decades to come, instead of making precise predictions of future concentrations, the IPCC has created various sets of scenarios meant to span a plausible range of possibilities for population, economy, technology, and so on. Recent versions of the scenarios are labeled by a number indicating the anthropogenic radiative forcing expected in 2100 under that scenario. Thus, a scenario labeled with a “6” corresponds to 6 W/m² of human-induced radiative forcing (warming) at the end of the century. (Recall current anthropogenic radiative forcing is about 2.7 W/m².)

Although the IPCC does not put its emission scenarios forward as forecasts they are often treated as such. Comparisons of past scenario groups against observations shows a tendency for IPCC emission projections to overstate actual subsequent emissions. For the IPCC Third and Fourth Assessment Reports a set of emission projections from the *Special Report on Emission Scenarios* were used and hence were referred to as the SRES scenarios. McKittrick *et al.* (2012) showed that, when converted to per capita terms, the SRES scenario distribution was skewed upwards and incompatible with observed trends. McKittrick and Wood (2013) further showed that global energy market dynamics constrained global per capita CO₂ emissions to an extent not reflected in IPCC scenarios. The bias of the SRES scenarios was confirmed by the later analysis in Hausfather *et al.* (2019) who showed that observed atmospheric CO₂ concentrations tracked the low end of the SRES range.

For the Fifth Assessment Report the IPCC developed a new set of scenarios called the Representative Concentration Pathways (RCP). These were identified by a number representing the increase in forcing and were thus called RCP2.6, RCP4.5, RCP6.0 and RCP8.5. RCP2.6 (implying a radiative forcing in 2100 of 2.6 W/m²) projects a GHG concentration pathway leading to warming well below 2°C. At the other end of the scale RCP8.5 is an extreme outcome implying nearly 5°C warming just in this century.

RCP8.5 came to be referred to as the no-policy baseline, or “business-as-usual” scenario in both the academic literature and popular media. It was therefore used to generate the reference outcome supposedly representing the 21st century world in the absence of emission reduction policies. But RCP8.5 was intended as a low-probability high emissions scenario and its usage as a business-as-usual baseline has been criticized as grossly misleading.¹ Hausfather and Peters (2020) writing in a commentary in *Nature* magazine, pointed out that RCP8.5 was developed as an extreme worst-case, and its misuse as a “business as usual” baseline has resulted in a large number of misleading studies and media reporting:

¹ This extreme scenario is useful for modelers, since a large forcing generates a large response (warming) making it easier to assess a model’s sensitivity. But that’s very different than claiming it is a plausible future.

RCP8.5 was intended to explore an unlikely high-risk future. But it has been widely used by some experts, policymakers and the media as something else entirely: as a likely 'business as usual' outcome. A sizeable portion of the literature on climate impacts refers to RCP8.5 as business as usual, implying that it is probable in the absence of stringent climate mitigation. The media then often amplifies this message, sometimes without communicating the nuances. This results in further confusion regarding probable emissions outcomes, because many climate researchers are not familiar with the details of these scenarios in the energy-modelling literature. (Hausfather and Peters 2020)

The implausibility of the RCP8.5 scenario was examined by Burgess *et al.* (2021). They noted that RCP8.5 has already diverged from observed energy use trends, and the near future trends diverge sharply from those of the International Energy Agency (IEA) which provides market-based projections of energy use for coming decades. IEA trends are based on plausible extrapolations of current economic and demographic trends, and the results run below the entire envelope of RCP projections, implying not only that RCP8.5 is dubious, but even lower emission scenarios are looking unlikely. Burgess *et al.* comment (p. 8):

Beyond 2040, if the trends anticipated by energy agency forecasts continue, carbon intensity will continue diverging from AR5 and SSP baselines—especially from higher-emission scenarios such as RCP8.5, due to the assumptions about fossil-fuel expansion in these scenarios that are increasingly implausible.

Widespread use of RCP8.5 has created an alarmist bias in the climate impacts literature. The extent of this problem was confirmed in a literature analysis by Felke Jr. and Ritchie (2020). They found (p. 32) that some 16,800 scientific papers published between 2010 and 2020 used the RCP8.5 scenario, with about 4,500 of the articles (p. 16) linking RCP8.5 with the concept of "business-as-usual". Their analysis showed how RCP8.5 was misused not only by individual researchers, but also by influential science agencies like the IPCC and the US National Climate Assessment (USNCA), which has directly led to misleading coverage in prominent media outlets. They offer the following example (p. 30):

The USNCA employed RCP8.5 as a baseline scenario, despite warning against such use, and compared it to RCP4.5 throughout its report to generate quantitative economic estimates of the benefits of mitigation. In a front-page story, the *New York Times* promoted the report's misuse of RCP8.5 as a baseline scenario:

"A major scientific report issued by 13 federal agencies on Friday presents the starkest warnings to date of the consequences of climate change for the United States, predicting that if significant steps are not taken to rein in global warming, the damage will knock as much as 10 percent off the size of the American economy by century's end."

Felke and Ritchie (2020) reported new studies using RCP8.5 were appearing in the literature at a rate of about 20 per day, with about two per day specifically linking RCP8.5 and "business as usual." They conclude (p. 34) that the climate research community has spent a decade "committing scientific resources to science fiction" (emphasis added):

“Derived estimates from RCP8.5 as “business as usual” such as future climate impacts, the impacts avoided from mitigation and the cost effectiveness and benefits of mitigation have no real-world meaning... **The scientific literature has become imbalanced in an apocalyptic direction.**
(Pelke Jr. and Ritchie p. 34)

The IPCC later converted the RCP scenarios to the “Shared Socioeconomic Pathway” or SSP scenarios, but these have continued the pattern of bias shown with the RCP and SRES scenarios. Figure 3.14 was generated using the Resources for the Future Global Energy Outlook tool (RFF 2025). The black line shows total global observed CO₂ emissions compiled by the International Energy Agency (IEA). The solid green line is the emission trajectory developed by BP Energy taking account of current emission control policies and global energy use outlooks. It overlaps a solid black line which represents the emission projection from the IEA also taking account of energy use projections and current policies. The dashed lines show the range of IPCC SSP policies. As of 2023 global CO₂ emissions have been tracking well below the SSP scenarios especially the two highest ones (SSP5-8.5 and SSP3-7.0).

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Carbon dioxide emissions (Million metric tons), by Outlooks & Scenarios. Filtered by Region: World; Fuel: All; Outlook: 2023 Shell (Sky 2050).

Source: RFF Global Energy Outlook at www.rff.org/geo

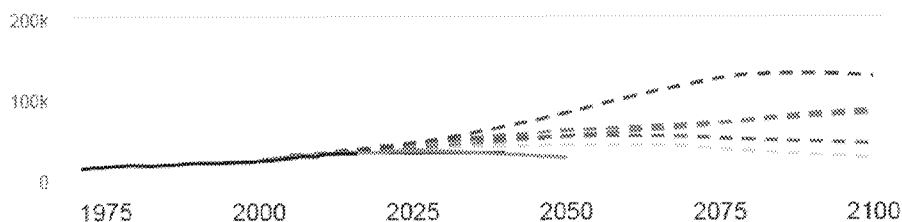


Figure 4.21. Observed and projected CO₂ emissions. Source: RFF (2025).

The carbon cycle relating emissions and concentrations

Global carbon cycle models relate concentrations to emissions using estimates of various land and ocean processes that remove CO₂ from, and emit CO₂ into, the atmosphere. Our understanding of these processes was reviewed by Crisp et al. (2021). The natural fluxes of CO₂ in and out of the Earth's surface are very large, many times anthropogenic emissions, but those CO₂ sources and sinks were assumed to be in approximate balance in pre-Industrial times, as evidenced by relatively constant levels of atmospheric CO₂ in centuries past derived

from air bubbles in ice cores. This is one of several reasons why increasing atmospheric CO₂ levels are believed to be dominated by anthropogenic sources.

Specifically, fossil fuel burning (and to a lesser extent land use [biomass burning] and cement production) has led to steadily increasing CO₂ levels in the atmosphere, as shown in Fig. 12.1. CO₂ emissions from fossil fuel burning is a small fraction of the natural carbon cycle components. About 44,000 Gigatonnes of carbon-equivalent (GtC) are stored in the atmosphere and oceans, mostly in the form of CO₂. (Ciais et al. 2013). Between 150 and 200 GtC are released naturally each year through oceanic outgassing and land-based processes like plant decay and animal respiration. A variable but roughly equivalent amount is absorbed each year by the land and oceans, with a small net loss from the atmosphere because the formation of deep ocean sediment sequesters some carbon permanently. Global fossil fuel consumption and cement manufacture released about 10.3 GtC in 2023, up from 6.2 GtC in 1990 (Ritchie et al. 2024). Of this, about half is naturally sequestered through plant growth and oceanic uptake while the remainder, about half, adds to the atmospheric stock (Ciais et al. 2013).

As noted, each year natural processes remove a net amount of CO₂ equivalent to about 50% of global emissions. Thus, anthropogenic CO₂ emissions average twice what is required to explain the atmospheric rise in CO₂ concentration. The near-constancy of that 50% fraction (the “airborne fraction”) also means that the more CO₂ humanity produces, the faster nature removes it from the atmosphere. That 50% fraction changes somewhat from year to year due to natural carbon cycle imbalances from El Niño, La Niña, and varying weather patterns. There was also a substantial additional reduction in atmospheric CO₂ after the 1991 eruption of Mt. Pinatubo, a curious result that has yet to be explained (Angert et al., 2004).

The main processes which remove excess CO₂ from the atmosphere are increased production of land vegetation (especially at high latitudes), some increase in the sequestering of carbon in soils, and uptake of CO₂ by the ocean due to the increasing partial pressure of atmospheric CO₂ over that of CO₂ dissolved in the ocean. All twenty land carbon cycle models tracked by the Global Carbon Project (Friedlingstein et al., 2024) show land processes have been removing excess CO₂ at an increasing rate since 1959. This is consistent with a “global greening” phenomenon observed by satellites since monitoring of global greenness began in the 1982. This greening has been traced to CO₂ fertilization and greater drought tolerance of plants exposed to elevated CO₂ levels. While there had been some uncertainty whether a greening trend continued beyond 2000, the most recent research (Chen et al., 2023) has shown continued greening, with even some slight acceleration since 2000. Global greening is discussed further in Section 3.1.

While land vegetation has been responding positively to more atmospheric CO₂, uptake of extra CO₂ by ocean biological processes remains too uncertain to be reliably measured. Our current understanding of these and many more carbon cycle processes was reviewed by Crisp et al. (2021).

Public policy can only change the rate of emissions, not the concentration in the atmosphere. For criteria air contaminants the rate and concentration are closely connected because the lifetime is short and the concentration is small. When emissions are reduced the local pollution concentration drops rapidly, usually on a time scale of a few days. Not so with the global average CO₂ concentration since global carbon cycle is vast and slow. A change in local emissions today will only have a very small global effect, and only after a long time lag. After a

pulse (release) of CO₂ emissions to the atmosphere only about 40 percent ($\pm 15\%$) of the extra CO₂ will have been sequestered after twenty years. After a thousand years about 75 percent ($\pm 10\%$) will have been sequestered, and the remainder will gradually be removed over the ensuing tens of thousands of years (Ciais et al. 2013, pp. 472-473). Consequently US CO₂ emission reductions will take decades or centuries to lead to a reduction in the global CO₂ concentration.

To reduce the atmospheric stock of CO₂, assuming the entire increase is anthropogenic, would require emissions to fall below the natural sequestration rate. Since that rate has been averaging about 50% of emissions, a reduction of global emissions by 50% would (at least temporarily) halt the rise in atmospheric CO₂. The 1997 Kyoto Protocol proposed to cap industrial nations' CO₂ emissions at a modest five percent below 1990 levels by the year 2012. Even though this policy ended up too costly for most nations to implement, full compliance would not have substantially reduced atmospheric CO₂ levels. It would only have slightly slowed CO₂ growth, reaching the projected 2100 level in 2105 instead (Wigley 1998). Similarly, Lomborg (2016) used the widely-used MAGICC climate model and showed that full compliance with the Paris Accord would not stop warming, it would only prevent about 0.1C warming and delay hitting the baseline year 2100 temperature levels by about a decade.

Thus, in contrast with conventional air pollution control, local actions yield extremely small local effects, and only after a long time lag. The practice of referring to unilateral US reductions as "combatting climate change" or "taking action on climate" reflects a profound misunderstanding of the scale of the issue. As will be discussed in Chapter 14, the scale problem is compounded by recognizing that US motor vehicles account only for about 4 percent of global CO₂ emissions so even a fifty percent reduction in those emissions would have a vanishingly small effect on the global climate.

4.3. Aerosols and the uncertainties associated with them

The climate's sensitivity to CO₂ (as quantified by ECS, the Equilibrium Climate Sensitivity²) is uncertain because the net forcing results from (at least) two counteracting components: warming from GHG's and cooling from aerosols. The observed warming can therefore be made to be consistent with a wide range of pairs of these forces. In the following schematic, the net warming represented by the red arrow could be due to the High GHG warming/strong aerosol cooling pair, or the Low GHG warming/weak aerosol cooling pair, or something in between.

² ECS is formally defined as the increase in equilibrium global average surface temperature resulting from a doubling of the atmospheric CO₂ concentration above its pre-industrial value of 280 ppm. Estimates of ECS are reviewed in Section XX.

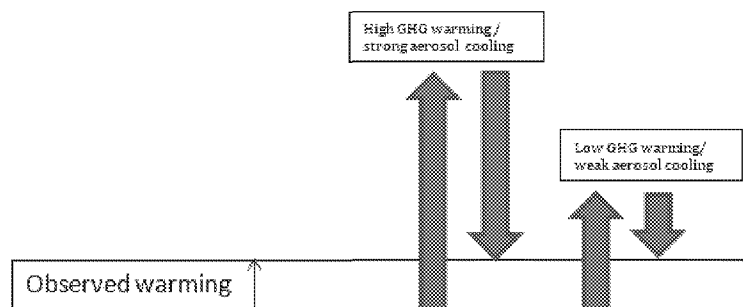


Figure 4.3.1: High and low climate sensitivity to GHGs can be reconciled with the same warming by assuming an offsetting aerosol cooling effect.

Research on the strength of aerosol cooling is therefore central to more precise ECS estimates. Lewis and Curry (2018) note that after the IPCC AR5 was published in 2013, eleven studies appeared in the scientific literature all finding that aerosol cooling was weaker than had previously been conjectured. Combining the updated aerosol estimates with greenhouse gas, ocean heat uptake and atmospheric warming data from the IPCC and applying standard empirical methods, Lewis and Curry (2018) estimated the best-guess ECS to be 1.66°C with a 95 percent uncertainty range of 1.15 °C – 2.7°C. They concluded that based on the ECS values derived from most IPCC climate models were incompatible with observed data.

There has been further evidence of lower aerosol cooling (implying lower ECS) such as Liu et al. (2021). These authors tested the hypothesis that aerosols from wildfires has increased since before the 20th century which, if true, would mean there had to have been relatively strong CO₂ warming over that period offsetting the aerosol cooling. They examined soot layers in ice cores extracted from Antarctica and South America and determined that wildfire activity prior to the 20th century was higher than previously believed. Instead of wildfire activity rising steadily from the 1700s to the present, it was high all the time, thus contradicting the hypothesized aerosol cooling trend in the Southern Hemisphere during the 20th century. They pointed out how this finding relates to the climate sensitivity issue:

Accurate estimates of aerosol radiative forcing are also crucial for better understanding the transient climate response (TCR) and equilibrium climate sensitivity (ECS) to increasing CO₂ and more accurate projection of future climate change. The negative aerosol radiative forcing can, in part, cancel out the positive forcing of increasing greenhouse gases and contribute to the uncertainty of total radiative forcing. An overly large aerosol cooling implies that models might overestimate TCR and ECS to reproduce historical temperature response. A recent study using one of the latest-generation CMIP6 climate models (E3SM) suggested that reducing both the magnitudes of negative aerosol radiative forcing and climate sensitivity yields a better agreement with the observed historical record of the surface temperature.

(Liu et al. 2021)

More evidence pointing to weak aerosol cooling was reported by Wang et al. (2021). They noted that the strength of aerosol cooling is partly mediated by cloud behavior and differs between the North and South Hemispheres because of the different density of aerosol emissions. This allowed them to construct another test of climate model validity, which came out in favor of low ECS models. In their words:

Since anthropogenic aerosols primarily concentrate in the Northern Hemisphere, strong aerosol-cloud interaction models produce an interhemispheric asymmetric warming. We show that the observed warming asymmetry during the mid to late 20th century is more consistent with low ECS (weak aerosol indirect effect) models.

Wang et al. (2021)

To summarize, quantifying warming due to CO₂ requires understanding the strength of aerosol cooling. While that latter is uncertain a substantial body of recent evidence points to it being relatively weak, implying that CO₂ warming is likewise weak.

Commented [SK5]: Can we offer any optimism about resolving this uncertainty?

Summary

- The global climate is naturally variable. Anthropogenic CO₂ emissions add to that variability by changing the total radiative balance in the atmosphere.
- The IPCC has downplayed the role of the sun in climate change but there are Total Solar Irradiance reconstructions that imply it might have been important, and the modern record is uncertain due to an interruption in satellite coverage.
- Projections of anthropogenic emissions are combined with carbon cycle model estimates of atmospheric CO₂ removal to estimate future CO₂ concentrations and hence the radiative forcings. These are input to climate models to estimate future anthropogenic changes in the climate.
- IPCC emission scenarios envelopes have tended to exceed observed trends.
- The vast majority of academic climate "impacts" studies in recent years are based upon the extreme RCP8.5 scenario that is considered implausible; its usage as a business-as-usual scenario is misleading.
- Despite ample evidence that scenario envelopes are exaggerated, and despite criticism of this practice in the peer-reviewed literature, the IPCC's most recent scenario set (SSP) perpetuates this malpractice.
- The global carbon cycle heavily dampens the effect of changes in local (e.g. U.S.) CO₂ emissions. Even global-scale emission reductions will have only small, much delayed effects.
- Knowing the magnitude of CO₂ warming requires knowing the strength of aerosol cooling. While that is uncertain, a substantial body of recent evidence points to it being relatively weak, implying CO₂ warming is likewise weak.

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Part II: Climate Response to Greenhouse Gas Emissions

5. Climate Sensitivity to CO2 Forcing

5.1. Introduction

The sensitivity of Earth's climate to increasing concentrations of CO₂ is at the heart of the scientific debate on anthropogenic climate change, and also the public debate on the appropriate policy response to increasing CO₂ in the atmosphere. Equilibrium Climate Sensitivity (ECS) refers to the expected amount of warming averaged over the Earth's surface in response to a doubling of CO₂, after all climate systems have had time to adjust. Some systems, like temperatures in the troposphere, adjust very rapidly, whereas others such as the deep ocean and ice sheets may take decades or even centuries. A related metric which is helpful for analysis on shorter time scales is the Transient Climate Response (TCR), defined as the amount of warming after 70 years in which atmospheric CO₂ increases by one percent annually.

In 1979 the Charney (1979) Report for the US National Academy of Sciences proposed that the most likely value for ECS was 3.0°C plus or minus 1.5°C. The ECS range between 1.5 and 4.5°C is characterized by the IPCC AR5 as the likely range (66 percent probability); the AR5 stated that ECS is extremely unlikely (95 percent probability) to be below 1.0°C and very unlikely (90 percent probability) to exceed 6.5°C. This range of ECS values has remained stubbornly wide, despite many individual studies claiming to narrow it. Most recently, the IPCC AR6 narrowed its assessment of the likely range of ECS to 2.5–4.0°C and the very likely range to be between 2.0 and 5.0°C. This narrowing of the range on the low end is disputed, as will be discussed below.

Uncertainties about ECS are highly consequential for policy making. As will be discussed in Chapter 13, economic models take the ECS value from climate science and use it to project the costs of CO₂ emissions. The traditional ECS value (3.0 °C) has typically yielded modest global social costs of CO₂ emissions, enough to justify some policy actions though mostly deferred to later in the century. If ECS is very high (4.5°C or above) aggressive immediate emission controls become more imperative, whereas values closer to 2.0°C have been shown to imply that no CO₂ emission controls are economically justifiable (Dayaratna et al. 2016, 2020). Obtaining a precise estimate is impossible, so policy making needs to account for the uncertainty.

5.2. Model-based methods of computing climate sensitivity to GHGs

The ECS ranges for the IPCC AR4 and AR5 were obtained primarily by examining the behaviour of climate models. For the AR6 the IPCC changed course and turned to a more direct data-driven methodology. Here we discuss some of the pitfalls of using climate models to try to determine the Earth's climate sensitivity.

ECS represents an emergent property of climate models—that is, it is not directly parameterized or tuned. However, collections of parameterizations are often chosen to produce an expected value of climate sensitivity, particularly with regards to sub-grid-scale cloud processes. Otherwise plausible models and parameter selections have been discarded because of

perceived conflict with this warming rate, or aversion to a model's climate sensitivity being outside an accepted range. For example, Mauritsen and Roeckner (2020) state the following regarding their Max Planck Institute climate model (emphasis added):

"We have documented how we tuned the MPI-ESM1.2 global climate model to match the instrumental record of warming; an endeavor which has clearly been successful. Due to the historical order of events, the choice was to do this practically by targeting an ECS of about 3 K using cloud feedbacks, as opposed to tuning the aerosol forcing."

In other words, the modelers chose an ECS value of 3°C and then tuned the cloud parameterizations to match their intended result.

Direct warming from CO₂ doubling is only about 1°C (Hall and Manabe 1997); further warming arises from climate feedbacks that are not explicitly resolved by the model but rely on parameterizations of physical processes. Higher values of ECS arise primarily from positive cloud feedbacks whose magnitude and even sign are very uncertain. Elements of cloud feedback include changes in the latitudinal distribution of clouds, changes in the distribution of cloud height (changes in low versus high clouds), changes to the phase of clouds (ice versus liquid), changes in cloud particle size (associated with changes in concentration and/or composition of aerosol particles), changes in the precipitation efficiency of clouds, and even changes in how clouds are distributed over the daily solar cycle (Curry and Webster, 1999). It is difficult for climate models to simulate any of these processes correctly owing to their small scale, let alone predict how they will change in the future. Further, cloud processes modulate the magnitudes of the water vapor, lapse rate, and the surface albedo feedbacks.

ECS can be determined from climate model simulations by doubling the concentration of CO₂ and allowing several centuries for the warming to equilibrate. To avoid the necessity of long simulations, "effective climate sensitivity" is commonly evaluated from a 150-year simulation in response to a sudden quadrupling of CO₂. The spread of ECS values from the CMIP5 climate models (used in the AR5) was 2.0–4.7°C; the spread has increased for the CMIP6 models (used in the AR6) to between 1.8 and 5.7°C (Chen et al, 2021). Far from the science being settled in relation to the response of the climate system to increasing greenhouse gas concentrations, insofar as it is represented by climate models, uncertainties appear to be growing. The main cause of the overall upward shift in ECS in CMIP6 relative to CMIP5 is a larger positive cloud feedback, driven by changes to the cloud parameterizations in many CMIP6 models (Zelinka et al., 2020).

Because of concerns about model tuning and the high sensitivity to cloud parameterizations, the IPCC AR6 (2021) did not rely on climate model simulations in their assessment of climate sensitivity, relying instead on other methods in its assessment instead, chiefly a recent empirical estimate.

5.3. Data-driven methods of computing climate sensitivity to GHGs

Climate sensitivity can also be estimated from instrumental records of surface temperatures and ocean heat content, combined with estimates of how climate forcings (e.g., greenhouse gases, solar, volcanoes, aerosols) have changed in the past (Otto et al, 2013). Using this information, a simple empirical model called an Energy Balance Model can be estimated. It requires estimating a feedback parameter whose uncertainties are highly amplified in the resulting ECS (Roe and Baker, 2007).

The accuracy of the data-driven methods depends on the quality of the input data. Assumptions are needed about ocean heat storage, and the ocean data is inadequate. The greatest source of uncertainty is the amount and composition of aerosol particles and their interactions with cloud radiative properties (the so-called aerosol indirect effect). Climate models exhibit warming in response to GHGs but cooling in response to aerosols (Schwartz et al. 2007). Observed 20th century warming can be shown to be consistent either with low ECS and low aerosol cooling, or high ECS and high aerosol cooling. Since fossil fuel use adds both GHGs and aerosols to the atmosphere, both effects need to be estimated to isolate the warming effect of CO₂. Over time, the IPCC's estimate of the cooling effect of aerosols has declined (Lewis 2022).

Paleoclimate proxies are also used to evaluate the sensitivity of past climates, by comparing paleoclimate changes in the Earth's temperatures to estimates of changes in forcings. The two most informative periods are the last glacial maximum (around 20,000 years ago), which was about 3–7°C colder than today, and a mid-Pliocene period (roughly three million years ago), which was 1–3°C warmer than today. The limits on cooling during the last glacial maximum give the best single evidence that high values of climate sensitivity are unlikely. However, paleoclimate estimates are associated with very large uncertainties in the estimated temperatures and forcings. Further, estimates of climate sensitivity based on past climate states may not be representative of the current state of the climate system.

A recurring theme in the climate literature is that ECS estimates based on historical data are smaller than ECS estimates inferred from climate models (Sherwood and Forest 2024). About 15 estimates based on historical data appeared in the peer-reviewed literature between 2012 and 2024 yielding ECS best estimates between 1.0°C and 2.5°C, although critics have questioned some of the methods and the data quality. For the AR6, the IPCC placed primary weight on the results of Sherwood et al. (2020) that combined historical and paleoclimate proxies and yielded a best estimate of 3.1°C. Lewis (2022) raised a number of concerns about this result, including methodological errors, outdated input values, and use of subjective versus objective Bayesian priors in the analysis. Lewis' analysis found that climate sensitivity is estimated to be much lower and better constrained than in the Sherwood et al. analysis – median 2.2°C (1.8–2.7°C in the 17–83 percent likely range, and 1.6–3.2°C in the 5–95 percent very likely range). The IPCC AR6 estimated only a 5 percent probability that ECS was below 2.3°C, whereas Lewis estimated it to be over 50 percent. The most recent publications on the debate between Sherwood et al. and Lewis further defend their respective positions: Sherwood and Foster (2024) and Lewis (2025).

An interesting footnote is that in 1983, the US National Research Council conducted a follow-up study to the 1979 Charney Report, and referring to the estimated sensitivity range of 1.5°C to 4.5°C, said:

"The climate record of the past hundred years and our estimates of CO₂ changes over that period suggest that values in the lower half of this range are more probable."

Nierenberg et al. (1983 p. 2)

Lewis' analysis likewise implies that climate sensitivity is likely in the lower half of the original 1979 Charney range.

A recent argument, which the IPCC AR6 emphasized, is that data-driven ECS estimates might understate the future warming response to GHGs based on a so-called "pattern effect" (Forster et al 2021). The tropical Pacific is believed to be highly influential on the overall efficiency with which the Earth's climate radiates heat to space, but in some regions heat is more efficiently removed from the climate system than from others. If in a warming climate there is a weakening of the west-to-east temperature gradient in the tropical Pacific, the result would be a concentration of warming in a region where heat is less efficiently removed, raising the ECS of the Earth's climate system. Most climate models simulate that rising GHGs will weaken the east-west temperature gradient, which led the IPCC in the AR6 to conclude that data-driven ECS estimates understated the future ECS value.

However, Seager et al (2019) pointed out that, contrary to models, the east-west temperature gradient has been strengthening rather than weakening over time. They further argued that the mechanism predicting otherwise in climate models was based on a faulty characterization of oceanic dynamics and there is no reason to expect the gradient to weaken. A similar argument was recently made by Lee et al (2024), who concluded that "the trajectory of the observed trend reflects the response to increasing GHG loading in the atmosphere"; in other words, GHG warming should lead to a future strengthening rather than a weakening of the temperature gradient. Increased efficiency of atmospheric cooling implies, if anything, that the future ECS in a warming climate may be lower than current estimates.

5.4. Transient Climate Response

The Transient Climate Response (TCR) is of greater utility in providing an observational constraint on climate sensitivity. TCR is the amount of warming that would occur at the time when CO₂ doubles, having increased gradually by 1 percent each year over a period of 70 years. Relative to the ECS, observationally-determined values of TCR avoid the problems of uncertainties in ocean heat uptake and the fuzzy boundary in defining equilibrium arising from a range of timescales for the longer-term feedback processes (e.g., ice sheets). TCR is more generally related to peak warming and better constrained by historical warming, than ECS. The IPCC AR6 judged the very likely range of TCR to be 1.2–2.4°C. In contrast to ECS, the upper bound of the TCR is more tightly constrained. For comparison, the TCR values determined by Lewis (2023) is 1.25 to 2.0°C, showing much better agreement with the AR6 values than was seen in a comparison of the ECS values.

A related but more flexible parameter is the Transient Response to cumulative carbon Emissions, or TCRE, which relates global temperature change to the cumulative emissions.

TCRE is based upon a linear relationship between global average temperature and cumulative emissions, which holds for cumulative emissions of up to 2 teratons of carbon. For a given value of TCRE, we can estimate the amount of warming expected over a future period in response to scenarios of cumulative carbon emission. The IPCC AR6 provides a very likely range for TCRE of 1.0–2.3°C, with a median value of 1.6°C.⁴⁸

As will be discussed in Chapter 6, a real-world ECS below the model average is supported by studies which show climate models on average estimate too much warming at the surface and in the troposphere compared to observations over the past 50 years. Also, lower values align with evidence from consistent fingerprinting (Section 8) that model responses to GHGs need to be scaled down quite a bit to align with observed trends.

5.5. Summary

In the past 5 years, there is a growing realization that climate models are not fit for the purpose of determining the sensitivity of the climate to increasing CO₂ (ECS), owing to the dependence of this sensitivity on poorly resolved processes related to clouds and water vapor.

Data-driven approaches using historical data and paleoclimate reconstructions are now regarded as more reliable for determining ECS, but their reliability is diminished by data inadequacies. The IPCC AR6 upper bound for the likely range of ECS is 4.0°C, lower than the AR5 value of 4.5°C. This lowering of the upper bound seems well justified by the paleoclimatic estimates of the ECS. The IPCC AR6 lower bound for the likely range of ECS is 2.5°C, substantially higher than the AR5 value of 1.5°C. This raising of the lower bound of the likely range of ECS has received a substantial challenge from the analysis of Lewis (2022, 2025) that finds the lower bound of the likely range to be 1.75°C with a median value of 2.2°C. Other lines of evidence supporting a lower bound on the ECS range below the IPCC AR6 value are discussed in Chapters 6 and 7.

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6. Models versus Observations in the Recent Past

6.1. Introduction

Climate models are the primary tool used to project future climate changes in response to increasing atmospheric levels of anthropogenic greenhouse gases. They provide the theoretical evidence underpinning energy policy changes, such as efforts to reduce carbon dioxide emissions. In order to determine the value of climate models for this purpose, it is reasonable to ask how well they have reproduced climate variations over the recent past, say the last half-century.

Of great concern is the fact that, after several decades of the climate modeling enterprise involving approximately three dozen models operated by research centers around the world, the range of future warming they produce in response to a hypothetical doubling of atmospheric CO₂ extends over a factor of three. This range of disagreement among models has not changed for decades.

Problems with climate models are not just in their disagreement over the future, but also in their ability to replicate the recent past. Here we review some of the most important metrics of climate model accuracy: ability to reproduce historical surface, tropospheric and stratospheric temperature trends, ability to reproduce the vertical warming profile and ability to reproduce other climate features such as snowfall and humidity. In all cases a persistent finding is that models on average err on the side of too much warming in response to observed historical forcings.

6.2. Surface warming

A straightforward test of climate model validity is its ability to reproduce historical warming in response to known past changes in climate drivers such as greenhouse gases. Figure 6.1 is reproduced from Scaffeta (2023), a peer-reviewed 2023 study which groups the latest-generation (CMIP6) climate models into low ECS (1.5 to 3.0 degrees C), medium ECS (3.0 to 4.5 degrees C) and high ECS (4.5 to 6.0 degrees C), and compares their post-1980 global average temperature simulation ranges to those of three surface temperature records and one satellite-based lower troposphere temperature data product.

Columns correspond to model groups showing low-ECS to high-ECS. Rows correspond to widely-used observed temperature records, the first three showing surface averages and the fourth showing the lower troposphere average. In each panel the yellow area denotes the mean and range ($\pm$ one standard deviation) of climate model simulations for that group. The thick black line shows the observed annual average temperature in the indicated source.

Examination of the leftmost column shows that the low-ECS models track the post-1980 historical warming record reasonably well, but the middle and right columns show that the medium- and high-ECS models conspicuously over-predict the warming.

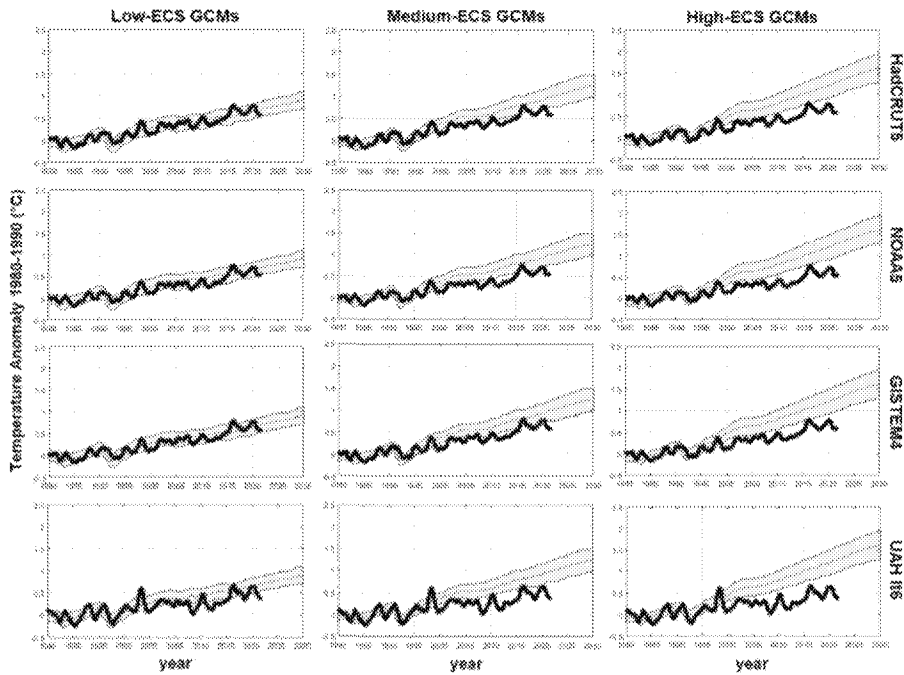


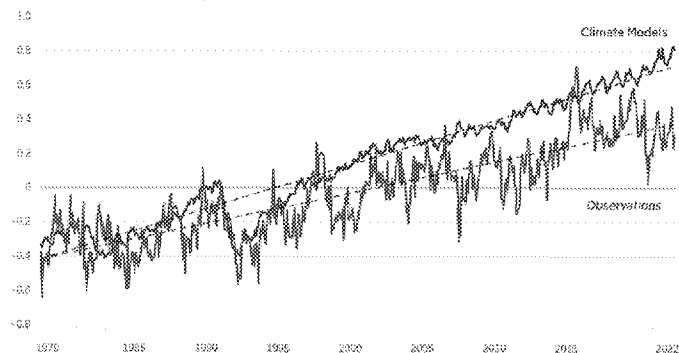
Figure 6.1: model-observational comparisons for Earth's surface warming. Source: Scafetta N. Climate Dynamics 2023 Fig.2. Rows: temperature data products as indicated. Columns: Low-to High-ECS models. Observations: black line. Model simulations: yellow band.

Spencer (2024) has also provided a useful summary of the Model-Observation mismatch by focusing on average surface temperature data products versus the average climate model warming, summarized in Figure 6.2.

CHART 1

Global Average Surface-Air Temperature Variations, 1979–2022

TEMPERATURE FROM 1951–2020 AVERAGE, IN DEGREES CELSIUS



NOTE: Figures have been adjusted to align trends starting in 1979.

SOURCES: Author's calculations based on data from five different observation-based datasets and 26 climate models taking part in the sixth IPCC Climate Model Intercomparison Project, and NOAA Climate Report, "Surface Trends," <https://climate.noaa.gov/start/surface> (accessed January 30, 2024).

Figure 6.2 Models versus observations at the surface. Source: Spencer (2024)

6.3. Tropospheric warming

It has long been known that climate models on average overstate warming in the troposphere over the tropics. Since this region generates the bulk of atmospheric warming in a GCM it is important to get the trends right. The discrepancy was flagged as a serious inconsistency in the first US Climate Change Science Program report (Karl et al. 2006) and has been mentioned in every IPCC report since, but it has gotten worse over time not better, and the bias is now global. McKittrick and Christy (2020) compare tropospheric warming rates in CMIP6 climate models to observations from satellites, weather balloons and reanalysis systems (Figure 6.3). Every single model overpredicts the observed warming trend in both Lower- and Mid-Troposphere layers, both globally and in the tropics (Figure 6.4).

In most individual cases the bias is statistically significant and on average it is highly significant. McKittrick and Christy (2020) also show that the bias is larger in high-ECS models, but even the models with lower average ECS predict too much warming. If a group of models were to appear that had a realistic representation of global tropospheric warming, it would likely have to have a lower ECS than even the low-ECS members of the CMIP6 ensemble.

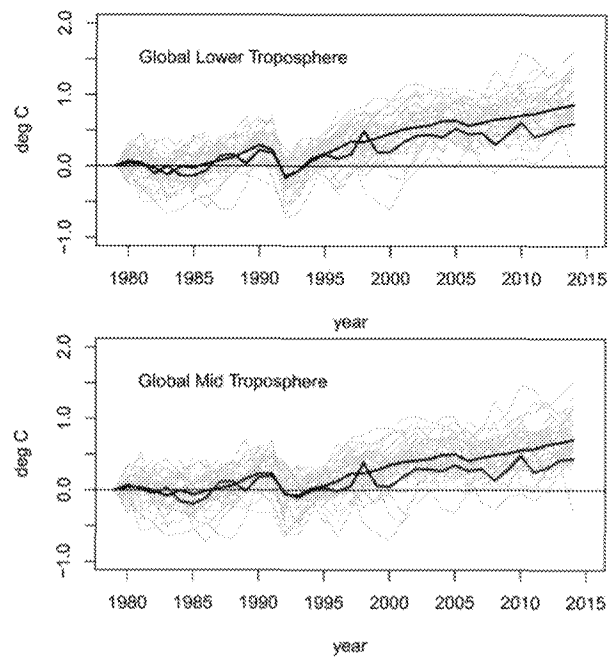


Figure 6.3: Models versus observations in the global troposphere. Source: McKittrick and Christy (2020). Gray lines: model runs. Black: average model run. Blue: average of satellite, radiosonde and reanalysis observations.

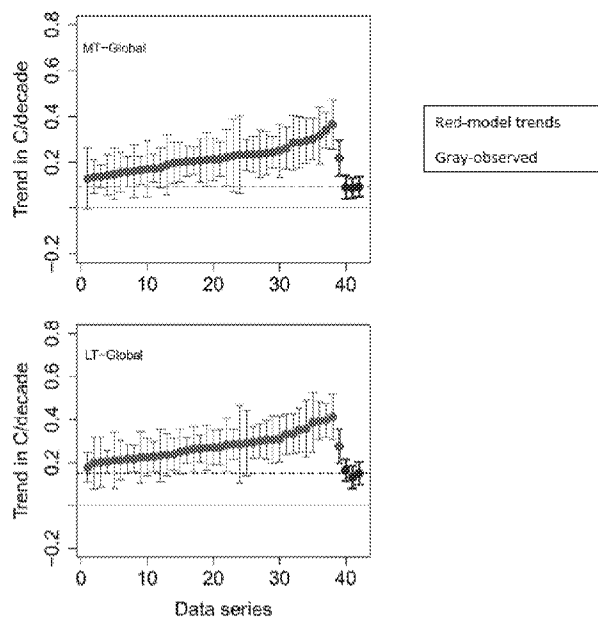


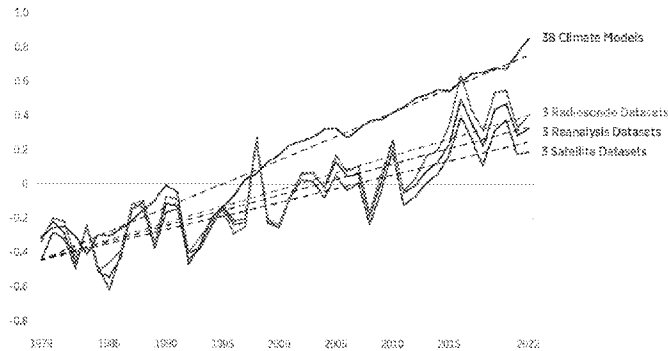
Figure 6.4: Modeled versus observed warming trends in the global troposphere. Adapted from McKittrick and Christy (2020). Red dots: model warming trend in $^{\circ}\text{C}/\text{decade}$ with 95% confidence interval bars. Gray dots: observed warming trends in 3 data products (satellite, radiosondes and reanalysis) and 95% confidence interval bars.

Spencer (2024) shows the mismatch is also present in the lower troposphere:

CPW061.1

Global Lower Atmospheric Temperature Variations, 1979–2022

TEMPERATURE FROM 1961–2020 AVERAGE, IN DEGREES CELSIUS



NOTE: Figures have been adjusted to align trends starting in 1979.

SOURCES:

- Author's conclusions based on data from Huai Ma et al. and John Christy, "Persistent Warming Bias in CMIP6 Troposphere Layers," *Earth and Space Science*, Vol. 7, No. 11, (July 15, 2020), <https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2019EA002076> (accessed January 10, 2023).
- Author's conclusions based on data from American Meteorological Society, *State of the Climate in 2022*, <https://www.ametsoc.org/index.cfm/press-publications/bulletin-of-the-american-meteorological-society-composite-of-the-climate/> (accessed January 8, 2023).

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Figure 6.5: Comparison of average trends in lower troposphere, 1979–2022. Source: Spencer (2024).

As mentioned the IPCC has long acknowledged the model-observational mismatch. The AR6 pp. 443–444 confirms model-observational mismatch in the troposphere the tropics (it does not address the global comparison):

Several studies since AR5 have continued to demonstrate an inconsistency between simulated and observed temperature trends in the tropical troposphere, with models simulating more warming than observations (Mitchell et al., 2013, 2020; Santer et al., 2017a, b; McKittrick and Christy, 2018; Po-Chedley et al., 2021)... Over the 1979–2014 period, models are more consistent with observations in the lower troposphere, and least consistent in the upper troposphere around 200 hPa, where biases exceed 0.1°C per decade. Several studies using CMIP6 models suggest that differences in climate sensitivity may be an important factor contributing to the discrepancy between the simulated and observed tropospheric temperature trends (McKittrick and Christy, 2020; Po-Chedley et al., 2021), though it is difficult to deconvolve the influence of climate sensitivity, changes in aerosol forcing and internal variability in contributing to tropospheric warming biases (Po-Chedley et al., 2021). Another study found that the absence of a hypothesized negative tropical cloud feedback could explain half of the upper troposphere warming bias in one model (Mauritsen and Stevens, 2015).

... In summary, studies continue to find that CMIP5 and CMIP6 model simulations warm more than observations in the tropical mid- and upper-troposphere over the 1979–2014 period (Mitchell et al., 2013, 2020; Santer et al., 2017a, b; Suárez-Gutiérrez et al., 2017; McKittrick and

Christy, 2018), and that overestimated surface warming is partially responsible (Mitchell et al., 2013; Po-Chedley et al., 2021). Hence, we assess with *medium confidence* that CMP5 and CMP6 models continue to overestimate observed warming in the upper tropical troposphere over the 1979–2014 period by at least 0.1°C per decade,

It is worth noting that despite the enormous accumulation of evidence of excess model warming the IPCC only assigns *medium confidence* to the existence of a warming bias. In other contexts they declare *high confidence* in phenomena established with much less evidence.

6.4. Vertical profile mismatch and excess amplification

An important element of the model-observational discrepancy is the excess amplification with altitude found in climate models. A comparison was shown in the IPCC AR5 Chapter 10, although only in the online supplement. The diagram, reproduced below as Figure 6.6, compares temperature trends by altitude between models and observations, divided up into latitude bands.

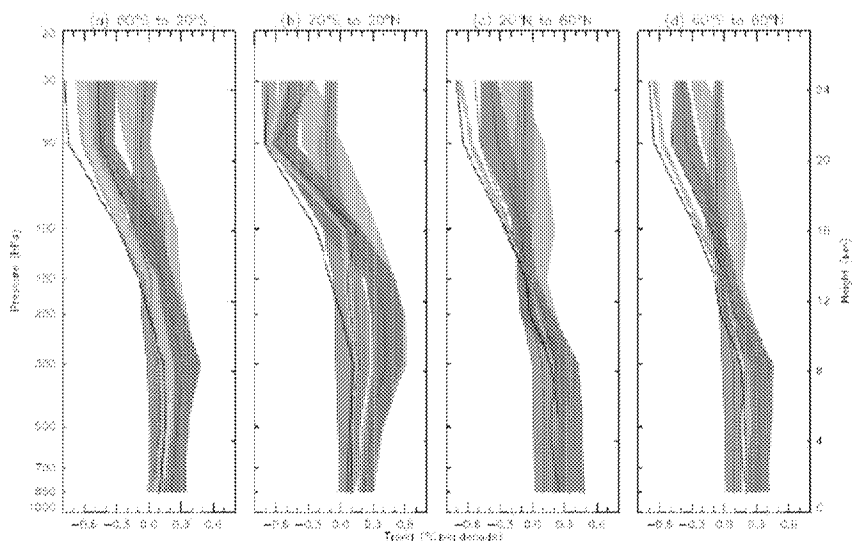


Figure 10.5M.1 | Observed and simulated zonal mean temperature trends from 1979 to 2010 for CMIP5 simulations containing both anthropogenic and natural forcings (red), natural forcings only (blue) and greenhouse gas forcing only (green) where the 5th to 95th percentile range of the ensembles are shown. Three radiosonde observations are shown: thick black line: Hadley Centre Atmospheric Temperature data set 2 (HadAT2); thin black line: Radiosonde Observation Intercomparison using RIASATv2 (RAOBICv2) 1.5; dark grey band: Radiosonde Observation Composite Homogenization (ROCH) v1.5 ensemble and light grey: ROCH v1.5 ensemble. (Adapted from Ioffe et al. (2013) but for the more recent period from 1979 to 2010.)

10588-6

Figure 6.6: Vertical warming pattern by latitude band. Source: PCC AR5 Figure 10.SM.1

The Figure is not referenced in the main report nor in any summary. What it shows, although it is not apparent at first glance, is that the 1979-2010 warming in the lower troposphere is so minimal it is consistent with models having no GHG forcing in them at all, and is inconsistent with the model runs that do have GHG forcing. Here is the main global band (60S to 60N) expanded with the observed trends highlighted in yellow:

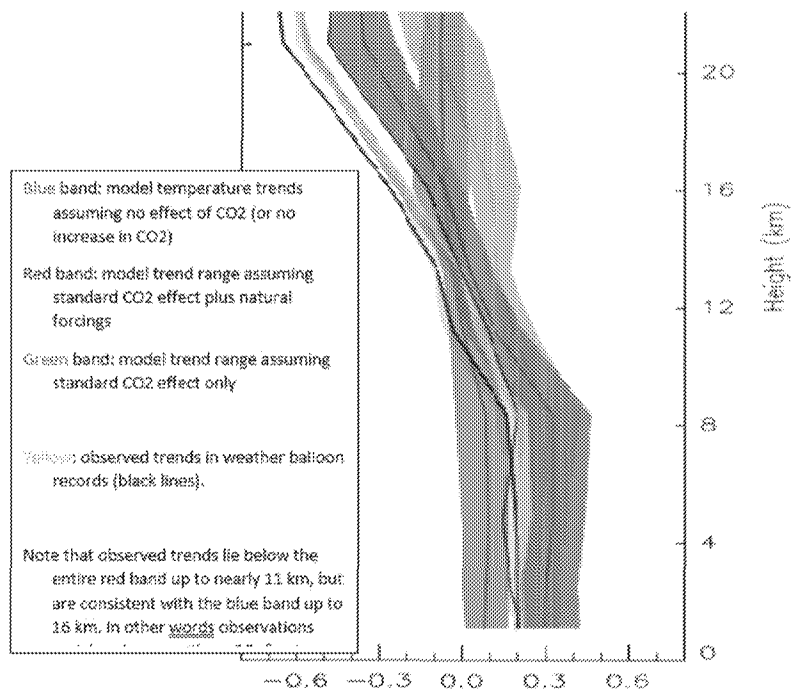


Figure 6.7: Adapted from IPCC AR5 Figure 10.SM.1

The next version of the Figure draws further detail out of the tropics band:

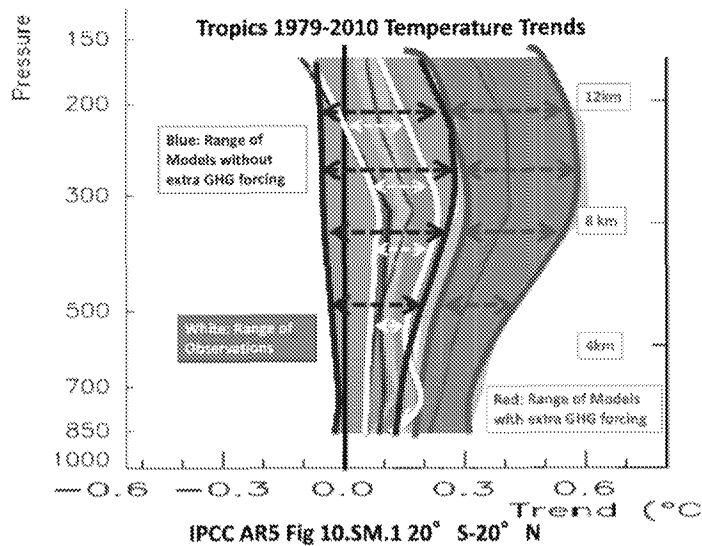


Figure 6.8: Adapted from IPCC AR5 Figure 10.SM.1.

In the tropics, where the models say the warming should be strongest, the observations (shown here in white) lie within the “No CO₂” band and entirely outside the “with CO₂” red envelope. This means that in the entire tropical atmospheric column from the surface to the stratosphere, observed warming trends are so small they are consistent with the output of models that have no CO₂ warming effect in them, and they are inconsistent with the entire envelope of warming trends generated by models forced with increased CO₂.

A similar comparison is shown in Christy and McNider (2017), an updated version of which (covering 1979-2024) is reproduced as Figure 6.9. Modeled temperature trends exceed balloon observations from the surface through the top of the troposphere, with observed trends below the entire model range at most pressure levels. Also shown in Figure 6.9 is the TTT layer average from three satellite data products (NOAA, UAH and RSS) compared to the same layer average from climate models for 1979-2024. Again the observed trends lie below the entire model range.

6.5. Stratospheric cooling

An important element of the expected general “fingerprint” of anthropogenic climate change is simultaneous warming of the troposphere and cooling of the stratosphere. The IPCC AR6 acknowledged that cooling had been observed but only up to 2000. Thereafter the stratosphere has exhibited some warming, contrary to model projections.

The AR6 WG1 Ch 2 pp. 327-9 states (emphasis added):

“Temperatures averaged through the full lower stratosphere (roughly 10–25 km) have decreased over 1980–2019 in all data products, with the bulk of the decrease prior to 2000. The decrease holds even if the influence of the El Chichon (1982) and Pinatubo (1991) volcanic eruptions on the trend, found by Steiner et al. (2020a) to have increased the 1979–2018 cooling trend by 0.06°C per decade, is removed. **Most datasets show no significant or only marginally significant trends over 2000–2019, and the results of Philipona et al. (2018) show weak increases over 2000–2015** in the very lowermost stratosphere sampled by radiosondes....

It is virtually certain that the lower stratosphere has cooled since the mid-20th century. However, most datasets show that **lower stratospheric temperatures have stabilized since the mid-1990s with no significant change over the last 20 years.** It is likely that middle and upper stratospheric temperatures have decreased since 1980, but there is low confidence in the magnitude.

The cited source, Philipona et al. (2018), in an article entitled “Radiosondes Show That After Decades of Cooling, the Lower Stratosphere Is Now Warming”, stated:

“In response to continued greenhouse gas increases and stratospheric ozone depletion, climate models project continued tropospheric warming and stratospheric cooling over the coming decades. Global average satellite observations of lower stratospheric temperatures exhibit no significant trends since the turn of the century. In contrast, an analysis of vertically resolved radiosonde measurements from 60 stations shows an increase of lower stratospheric temperature since the turn of the century at altitudes between 15 and 30 km and over most continents. Trend estimates are somewhat sensitive to homogeneity assessment choices, but all investigated radiosonde data sets suggest a change from late twentieth century cooling to early 21st century warming in the lower stratosphere.”

6.6. Water vapour trends

Much of the warming in climate models derives not from GHG increases themselves but from water vapour feedbacks: extra warming induced by the projected accumulation of water vapour in the atmosphere after it warms due to CO₂. But new evidence (Simpson et al. 2024) shows that models have over-projected increases in humidity.

"Water vapor in the atmosphere is expected to rise with warming because a warmer atmosphere can hold more moisture. However, over the last four decades, near-surface water vapor has not increased over arid and semi-arid regions. This is contrary to all climate model simulations in which it rises at a rate close to theoretical expectations, even over dry regions. This may indicate a major model misrepresentation of hydroclimate-related processes; models increase water vapor to satisfy the increased atmospheric demand, while this has not happened in reality."

(Simpson et al. 2024)

While the models and observations matched over the 1988 to 2006 interval they diverge after that, directly contradicting model projections.

6.7. Snow cover

According to the Rutgers University Snow Lab (undated) the Northern Hemisphere winter snow cover shows an increasing trend over time.

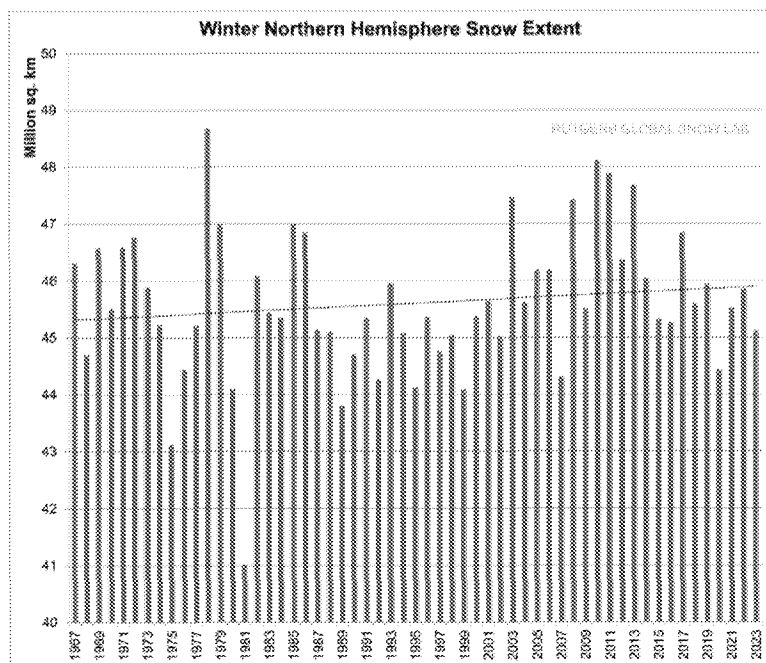


Figure 6.10: Northern Hemisphere Winter Snow extent. Source: [[HYPERLINK
"https://climate.rutgers.edu/snow-cover/chart_seasonal.php?ui_set=nhl&ui_season=1"](https://climate.rutgers.edu/snow-cover/chart_seasonal.php?ui_set=nhl&ui_season=1)]
(February 24, 2024)

Models project declining Northern Hemisphere snow cover due to climate warming. But observations do not support this, as explained by Connolly et al. (2019).

Observed changes in Northern Hemisphere snow cover from satellite records were compared to those predicted by all available Coupled Model Intercomparison Project Phase 5 ("CMP5") climate models over the duration of the satellite's records, i.e., 1967–2018. A total of 196 climate model runs were analyzed (taken from 24 climate models). Separate analyses were conducted for the annual averages and for each of the seasons (winter, spring, summer, and autumn/fall). A longer record (1922–2018) for the spring season which combines ground-based measurements with satellite measurements was also compared to the model outputs. The **climate models were found to poorly explain the observed trends. While the models suggest snow cover should have steadily decreased for all four seasons, only spring and summer exhibited a long-term decrease, and the pattern of the observed decreases for these seasons was quite different from the modelled predictions.** Moreover, the observed trends for autumn and winter suggest a long-term increase, although these trends were not statistically significant.

Connolly et al. (2019), emphasis added

6.8. US Corn Belt

One of the largest discrepancies between models and observations can be found when we test them in a region of particular importance to global food production: the U.S. Corn Belt. Fig. 6.11 shows the warming trends for summertime (June, July, August) for the U.S. 12-state Corn Belt (IN, IA, NE, ND, SD, MO, MN, WI, MI, OH, KS, NE) during 1973–2022. All 36 climate models (red) produced too much warming compared to observations (blue) during 1973 to 2022.

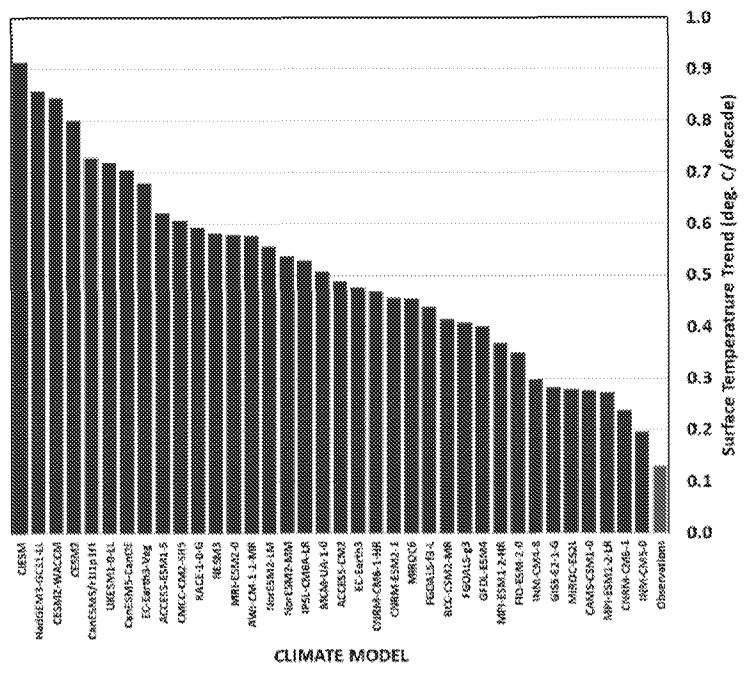


Figure 6.11: Modeled versus observed warming trends in the US corn belt.

As discussed in Chapter 10, the anticipated negative effects of increasing temperatures on U.S. corn yields have not materialized, which is in contrast to widely publicized studies proclaiming that theoretical future impacts are already being experienced (e.g. Seager et al, 2017).

Summarizing:

- Climate models show warming biases in many aspects of their reproduction of the past few decades.
- They produce too much warming at the surface (except in the models with lowest ECS), too much warming in the lower-and mid-troposphere and too much amplification of warming aloft
- They also produce too much stratospheric cooling, too much water vapor increase, too much snow loss, and too much warming in the corn belt.
- The IPCC has acknowledged some of these issues, buried the amplification problem and ignored others.

- The warm bias discussed here is consistent with independent evidence of model bias presented in Chapters 5 (measuring climate sensitivity) and 7 (optimal fingerprinting). Given the persistent warm bias in so many key aspects of climate model performance, users are justified in assuming that projections of future warming are also very likely to be biased too warm.

7. Uncertainties in Climate Change Attribution

7.1. Introduction

The Intergovernmental Panel on Climate Change (IPCC) distinguishes between detection of climate change and attribution of cause. As defined by the IPCC AR6 WGI Glossary (IPCC, 2025):

Detection: "Detection of change is defined as the process of demonstrating that climate or a system affected by climate has changed in some defined statistical sense, without providing a reason for that change. An identified change is detected in observations if its likelihood of occurrence by chance due to internal variability alone is determined to be small, for example, <10%."

Attribution: "Attribution is defined as the process of evaluating the relative contributions of multiple causal factors to a change or event with a formal assessment of confidence."

Both steps rely on statistical analysis. Detection focuses on whether changes are significant enough to stand out from random variation regardless of cause. Attribution involves comparison of observed events to model-generated counterfactuals. Since experimentation on the climate is not possible attribution requires statistical inference to assess how much human activities, such as GHG emissions, versus natural factors, like volcanic eruptions, explain observed changes. Attribution methods assume all external and internal drivers of the system are known and represented.

There are ongoing scientific debates around attribution methods, especially for attributing extreme weather events to climate change. The IPCC has long cautioned that methods to establish causality in climate science are inherently uncertain and ultimately depend on expert judgement. The Fourth Assessment Report: The Physical Science Basis (Hegerl et al., 2007) explained it as follows:

'Attribution' of causes of climate change is the process of establishing the most likely causes for the detected change with some defined level of confidence... unequivocal attribution would require controlled experimentation with the climate system. Since that is not possible, in practice attribution of anthropogenic climate change is understood to mean demonstration that a detected change is 'consistent with the estimated responses to the given combination of anthropogenic and natural forcing' and 'not consistent with alternative, physically plausible explanations of recent climate change that exclude important elements of the given combination of forcings' (IPCC, 2001)... The approaches used in detection and attribution research described above cannot fully account for all uncertainties, and thus ultimately expert judgement is required to give a calibrated assessment of whether a specific cause is responsible for a given climate change.

The Fifth Assessment Report Working Group II makes the following statement: (Cramer et al., 2014):

"Two broad challenges to the detection and attribution of climate change impacts relate to observations and process understanding. On the observational side, high-quality, long-term data relating to natural and human systems and the multiple factors affecting them are rare. In addition, the detection and attribution of climate change impacts requires an understanding of the processes by which climate change, in conjunction with other factors, may affect the system in question."

Because of the complexity of the causal chains in the climate system, investigation of these relationships is exceptionally challenging.

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7.2 Attribution methods

The Intergovernmental Panel on Climate Change (IPCC) employs several attribution methods to assess the causes of observed climate changes, distinguishing between natural and human-induced factors. Below is a concise description of the key methods that have been used by the IPCC:

Optimal Fingerprinting uses linear regression to explain variations in observed climate data as a weighted sum of climate model simulations run with and without anthropogenic forcings. The data used in the regression model are weighted to try to minimize the influence of random noise and the estimation method is chosen to take account of climate model error.

Time Series Analysis exploits statistical differences between anthropogenic forcing and natural variability to see which one dominates observed temperatures, and also uses variations in the timing of changes to determine if causal dependence across data series can be inferred.

Process-Based Attribution focuses on understanding the physical mechanisms behind observed changes. This approach combines observations, climate models, and theoretical understanding to attribute changes in specific processes to forcings. This approach is often used for regional climate phenomena, such as monsoon changes or polar amplification.

Extreme Event Attribution assesses the role of human influence in the likelihood of occurrence or intensity of extreme weather events (e.g. heat waves, droughts). Methods include:

Probabilistic Event Attribution uses large ensembles of climate model simulations to compare observed events to model-generated counterfactuals.

Storyline Approach examines the physical processes driving an event and evaluates how anthropogenic forcings may have modified those processes.

7.3 Attribution of global warming

Attribution statements for global warming in the three most recent IPCC Assessment reports are:

AR4: "Most of the observed increase in global average temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic greenhouse gas concentrations." (IPCC, 2007)

AR5: "It is *extremely likely* that more than half of the observed increase in global average surface temperature from 1951 to 2010 was caused by the anthropogenic increase in greenhouse gas concentrations and other anthropogenic forcings together. The best estimate of the human-induced contribution to warming is similar to the observed warming over this period." (IPCC, 2013)

AR6: "The *likely* range of total human-caused global surface temperature increase from 1850–1900 to 2010–2019 is 0.8°C to 1.3°C, with a best estimate of 1.07°C. It is *likely* that well-mixed GHGs contributed a warming of 1.0°C to 2.0°C, other human drivers (principally aerosols) contributed a cooling of 0.0°C to 0.8°C, natural drivers changed global surface temperature by –0.1°C to +0.1°C, and internal variability changed it by –0.2°C to +0.2°C. It is *very likely* that well-mixed GHGs were the main driver of tropospheric warming since 1979." (IPCC, 2021)

The AR4 and AR5 attribution statements reference the warming since the mid-20th century, the period when greenhouse gas emissions began rapidly increasing. The words "most" and "more than half" are deliberately imprecise, potentially ranging from 51 to 99% of the warming – presumably this imprecision is to account for structural uncertainties such as natural internal variability. The confidence level increases from *very likely* to *extremely likely* from AR4 to AR5. The structure of the attribution statement in the AR6 is fundamentally different, referencing the warming to the period 1850–1900. The AR6 attribution statement is more precise numerically, but with a lower level of confidence at "likely" – the AR6 attributes essentially all of the warming to increases in greenhouse gases. The most confident statement from the AR6 relates to the tropospheric warming since 1979, using the words "main driver" and "very likely."

There are three areas of substantive criticism of the IPCC assessment of the causes of the recent warming: inadequate assessment of natural climate variability, inappropriate statistical methods, and substantial discrepancies between models and observations. The latter is discussed in Chapter 7. The other two factors are discussed herein. Both of these issues are relevant not only in context of the main policy-relevant statement of the IPCC concerning attribution of the recent warming, but also because the global warming attribution provides the basis for extreme event attribution.

7.2. Natural climate variability

The IPCC AR6 states that natural external drivers since 1850–1900 have changed global surface temperature by –0.1°C to +0.1°C, and internal variability has changed it by –0.2°C to +0.2°C – on average, having essentially no net impact on the warming since 1850–1900. This assessment of the contributions of natural variability has been disputed by a number of publications that question the magnitudes of the contributions from solar forcing and internal variability from the large-scale ocean circulations (R Connolly et al., 2021; W Soon, 2023).

If the Equilibrium Climate Sensitivity to CO₂ is low (Chapter 5), then natural climate variability becomes more important in the attribution of the recent warming. Further, if natural variability is higher, then estimates of the Equilibrium Climate Sensitivity from the historical period would be lower (Scafetta, 2023).

Solar variability

The IPCC AR5 concluded that the best estimate of radiative forcing due to Total Solar Irradiance (TSI) changes for the period 1750–2011 was 0.05 W/m² (Myrhe et al., 2014). The IPCC AR6 acknowledges a much larger range of estimates of changes in TSI over the last several centuries, stating that the TSI between the Maunder Minimum (1645–1715) and the second half of the twentieth century increased by 0.7–2.7 W/m², a range that includes both low and high variability TSI data sets (Gulev, 2021). However, the recommended forcing dataset for the CMIP6 climate model simulations used in the AR6 for attribution studies averages two data sets with low solar variability (Matthes, 2017).

While the IPCC AR6 shows a substantially greater solar impact than does the AR5, the overall impact on the climate was assessed to be small compared to anthropogenic forcing of climate change. However, the impact of solar variations on the climate is uncertain and subject to substantial debate – something that you would not infer from the IPCC assessment reports (Lockwood, 2012; Connolly et al., 2021).

Exactly how TSI has changed over time has been a challenging problem to resolve. Since 1978, there have been direct measurements of TSI from satellites. However, the data exhibit non-negligible inconsistencies, and interpreting any multi-decadal trends in TSI requires comparisons of observations from overlapping satellites. There are several rival composite TSI datasets, disagreeing as to whether TSI increased or decreased during the period 1986–96 (the ACRIM gap; see Chapter 4). Further, the satellite record of TSI is used for calibrating proxy models, whereby past solar variations are inferred from sunspots and cosmogenic isotope measurements (Velasco Herrera et al., 2015).

There is substantial evidence for high solar activity in the second half of the 20th century (starting in 1959) and extending into the 1990's, before a decline in the early 21st century; this period is often termed the "Modern Maximum." (Chatzistergos et al., 2023; Solanki et al., 2004; Usoskin et al., 2007). However, some scientists have concluded that it is not possible to be confident of any multi-decadal trend in TSI (Schmutz, 2021).

As a result of this uncertainty, some reconstructions for past values of TSI (since 1750) have low variability, implying a very low impact of solar variations on global mean surface temperature, whereas datasets with high TSI variability can explain more than 70% percent of the temperature variability since preindustrial times (Scafetta, 2013; Stefani, 2021). Hence, the choice of which TSI satellite record used in an analysis can substantially influence how much climate change is attributed to human versus natural forcings.

There is growing evidence that other aspects of solar variability, which are referred to as solar indirect effects, amplify TSI forcing or are independent of TSI forcing. Scafetta et al. (2023) suggests that ~80% of solar influence on climate may stem from non-TSI mechanisms.

Candidate processes include: solar ultraviolet changes; energetic particle precipitation; atmospheric-electric-field effect on cloud cover; cloud changes produced by solar-modulated galactic cosmic rays; large relative changes in the magnetic field; and the strength of the solar wind. Solar indirect effects are not included in climate models, although indirect methods of estimating these effects suggest significant influence. However, claims of non-TSI mechanisms influencing climate are uncertain and debated.

Natural variability of large-scale ocean circulations

Variations in global mean surface temperature are linked to recurrent large-scale variations in ocean circulation patterns. These circulation patterns include the Atlantic Multidecadal Oscillation (AMO), the Pacific Decadal Oscillation (PDO) and the El Niño-Southern Oscillation (ENSO). These circulation patterns influence ocean heat uptake and heat distribution, and also influence atmospheric circulation patterns and cloud distributions. There is some debate as to whether these variations are strictly internal to the climate system, or whether this variability can have a solar/astronomical origin or can be influenced by large volcanic eruptions.

While climate models simulate the large-scale ocean circulations and internal climate variability, the simulated magnitude in the multi-decadal band is too low in most models relative to observations, and the phasing of the variability in long-term climate simulations is not synced with the actual, observed climate variations (Kravtsov et al. 2024). Averaging multiple simulations from climate models effectively averages out the internal variations, leaving only the forced climate variability (e.g., CO₂ forcing). With most of the modern warming beginning in the late 1970's, the recent 50-year warming is on the same time scale as the multi-decadal oscillations of the AMO and PDO.

Here are summary statements from the IPCC AR5 and AR6 reports:

"Decadal variability in the Pacific, associated with the PDO or IPO, contributes significantly to regional and global temperature trends, but the relative contributions of internal variability and external forcing are difficult to disentangle in CMIP5 simulations." (IPCC, 2013)

"Since AR5, there has been increased understanding of the role of internal variability, such as ENSO, PDO, and AMO, in modulating regional climate trends. However, limitations in simulating the exact timing and amplitude of these modes in CMIP6 models contribute to uncertainties in attributing observed changes to anthropogenic forcing (high confidence)." (IPCC, 2021)

The amplitude of the peak-to-trough impact of the multi-decadal oscillations on global temperatures has been assessed by the IPCC AR6: "The likely range of change due to internal variability is -0.2°C to +0.2°C (IPCC, 2021)." This implies a trough-to-peak change of 0.4°C. Over many centuries, any global temperature changes from the troughs and peaks will cancel out, with little to no net impact.

However, with a nominal timescale of 60-80 years for oscillations such as the AMO and PDO, the timing of the peaks and troughs can be confused with the secular trend. This becomes very relevant for attributing the warming for the 50 years since 1975, during which most of the

warming has occurred. Even if climate models have the correct amplitude of the multidecadal oscillations, the timing of the peaks and troughs is not adequately simulated, with each model and individual ensemble simulating a different phasing. Once the simulations of the ensemble members and different models are averaged, the natural internal variability contribution is averaged out, effectively cancelling the role of natural internal variability in the attribution process.

The Great Pacific Climate Shift of 1976-1977 was a notable climatic event characterized by an abrupt change in the North Pacific Ocean's atmosphere-ocean system that interacted with global climate patterns. This shift is closely associated with the Pacific Decadal Oscillation (PDO) that oscillates between warm and cool phases over decades. The 1976 shift marked a transition from a predominantly negative (cool) PDO phase (1947-1976) to a positive (warm) phase (1977 through 2000), with significant implications for global and regional climate patterns including the frequencies of El Niño and La Niña events. The Great Pacific Climate Shift coincided with the beginning of a period of accelerated global warming (REF TO A FIG OF GLOBAL TEMP ANOMALIES ELSEWHERE IN DOC). When the Great Pacific Climate Shift is accounted for in climate attribution analyses since 1950, it has been found that 40 percent or more of the warming in the second half of the 20th century was caused by natural internal variability (McLean et al, 2009; Tung and Zhou, 2013; Chylek et al., 2016; Scafetta, 2021).

7.3. Optimal fingerprinting

Optimal fingerprinting is a statistical technique introduced by Allen and Tett (1999) that compares observed climate data to climate model simulations to identify patterns (or "fingerprints") associated with human or natural forcing. It involves taking a vector of observed climate changes, such as warming rates in locations around the world, and decomposing them into a weighted sum of "signals", which are analogues to the observations generated by climate models with different types of forcings. The weights are chosen using a regression method called Total Least Squares. The analysis commonly uses just two signals, one generated by models using only anthropogenic forcings and one using only natural forcings. If the estimated weighting coefficient attached to a signal is significantly different from zero, then that signal is said to be "detected". If it is close to 1.0, then the model generating the signal is said to be consistent with observations. If it is less than 1.0, then the model signal for that forcing is too strong and needs to be scaled down, and vice-versa. Both the observed data and the signals are weighted using a model-generated estimate of patterns of randomness in the climate system so as, in principle, to put maximum weight on regions where natural variability is minimized.

Optimal fingerprinting is the primary tool for attribution in the climate literature. Studies applying it have been cited thousands of times, and it has been prominently featured by the IPCC since the 2001 Third Assessment Report. One of its inherent weaknesses is that results depend on assumptions about the accuracy of climate models, especially regarding their representation of natural variability (IPCC AR5 Ch 10.2.3).

Additionally, a series of papers by McKittrick (McKittrick 2022a, 2022b, 2023, 2025) has challenged the optimal fingerprinting method, arguing that it is inherently unreliable and that commonly used practices in econometrics can provide more valid results. Statistical theory

requires that for regression models to yield unbiased coefficients, a set of assumptions called the Gauss-Markov conditions must hold. McKittrick (2022a) argued that the Allen and Tett (1999) methodology violates the Gauss-Markov conditions, leading to potentially biased and inconsistent fingerprinting coefficients, undermining the reliability of the method. Chen et al. (2023) confirmed this analysis and argued that the method could yield unbiased results but only under very stringent assumptions. McKittrick (2022b) and (2023) raised a further concern that climate scientists—virtually alone among scientific disciplines—have used an estimation method called Total Least Squares (TLS) to estimate anthropogenic greenhouse gas signal coefficients, despite its tendency to be unreliable unless some strong assumptions hold that in practice are unlikely to be true. Under conditions which easily arise in optimal fingerprinting, TLS yields estimates with large positive biases. Thus, any study that has used TLS for optimal fingerprinting without verifying that it is appropriate in the specific data context has likely overstated the result.

McKittrick (2025) presented an empirical example comparing the results of conventional optimal fingerprinting against methods drawn from mainstream econometrics which are known to be valid for the specific application of signal detection. While the IPCC optimal fingerprinting method yields an anthropogenic signal coefficient close to 1.0 on a global temperature data set spanning 1900 to 2010, consistent estimation yields a coefficient around 0.4, which rises to about 0.65 on data spanning 1980 to 2010, implying the model response to greenhouse gases needs to be scaled down by about half to optimally match observations. The natural forcing signal coefficient, by contrast, is between 2.0 and 4.0, implying the climate model signals of natural forcing need to be scaled up two-to four-fold to match observed climate change. The fingerprinting coefficients estimated in McKittrick (2025), when used to scale the average sensitivity of the climate models used to generate the forcing signals in his data set, imply a Transient Climate Sensitivity of 1.4°C, which matches the estimate by Lewis (2022) using a different estimation method and multiple independent data sets.

While these analyses do not prove that all of the results from using the IPCC optimal fingerprinting method are wrong, it does show that the basis on which they were believed to be correct is non-existent – hence reducing confidence in the results.

7.4. Time series methods

The IPCC (AR5 WGI 10.2.2) drew attention to alternative approaches of assessing causality that emerged from the time series econometrics literature. They have the advantage of not depending on assumptions about the accuracy of climate models, but their disadvantage is they depend on assumptions about the data generating process underlying climate and forcing data that are not straightforward to test. The methods, now referred to as climate econometrics, use the tools of unit root testing, Granger causality and cointegration analysis, all of which are familiar in economics and finance and which are slowly being adopted in climate science. Time series analysis methods hold out the possibility of determining whether anthropogenic or natural forcings are the primary drivers of climate change without requiring the use of climate models, although key questions remain unsettled (e.g. Dergiades et al. 2016, Balcombe et al. 2019, Dagsvik et al. 2020, Razzak 2022, Dagsvik and Mben 2023).

Granger causality modeling is a tool for determining directions of influence in data series that move together. "Granger causality" is a statistical, not a physical, concept. If knowing the current value of one variable significantly improves the forecast accuracy of another variable we can infer a causal connection exists; this is called Granger causality. The modeling tools, called vector autoregression, measure direct impulse-response patterns and feedbacks. An application to the well-known Vostok ice core data revealed an error by Al Gore in his documentary *An Inconvenient Truth*. Gore showed the data and drew attention to the coherence of temperature and CO₂ changes over a 440,000 year span, which he asserted was due to CO₂ driving temperature changes. But temperature changes can also affect atmospheric CO₂ levels. Davidson et al. (2015) examined the series and found that temperature Granger causes CO₂ but not the reverse. In other words on the time scales represented in the Vostok data the coherence in the series is primarily due to the influence of temperature on CO₂ levels not the feedback going from CO₂ to temperature.

In summary, the main statistical methods for attributing causation in climate data are optimal fingerprinting and time series analysis. Applications of the Allen and Tett (1999) optimal fingerprinting method dominate the attribution literature and have underpinned past IPCC conclusions, but results depend on the accuracy of climate models and the method has recently been criticized as inherently biased. Time series methods do not depend on climate models but require assumptions of their own and have generated results that have thus far not converged on a consensus.

7.5. Extreme event attribution (EEA)

The IPCC AR6 provides an ambiguous assessment of the role of global warming in the historical record of extreme weather and climate events. Chapter 11 of WG1 states (Seneviratne et al., 2021):

"Evidence of observed changes in extremes and their attribution to human influence (including greenhouse gas and aerosol emissions and land-use changes) has strengthened since AR5, in particular for extreme precipitation, droughts, tropical cyclones and compound extremes (including dry/hot events and fire weather). Some recent hot extreme events would have been extremely unlikely to occur without human influence on the climate system."

By contrast, Chapter 12 of WG1 (Table 12.12) paints a different picture – presumably, the expert judgment of different groups of authors for the two chapters came to different conclusions (Ranasinghe, 2021):

High confidence in an increase in extreme heat events in tropical regions where observations allow trend estimation and in most regions in the mid-latitudes, medium confidence elsewhere

Medium confidence in a decrease in extreme cdd events in Australia, Africa and most of northern South America where observations allow trend estimation

No evidence of emergence in the historical period of a change in river floods, heavy precipitation, drought, fire weather, severe wind storms, and tropical cyclones

While the overall issue of detecting changes in extreme weather events and their attribution remains ambiguous, most of the activity in this area relates to the attribution of single extreme weather events. The most prominent effort is the World Weather Attribution (WWA; worldweatherattribution.org), which is an international research initiative that focuses on extreme event attribution analyzing how climate change influences the likelihood and intensity of extreme weather events. The approach used by the WWA runs large ensembles of regional climate models to compare the event in today's climate, versus a pre-industrial counterfactual climate without human-caused warming.

WWA plays a prominent role in linking extreme weather to climate change and its press releases attract considerable public and policy discussions. However, the WWA's tendency to promote non-peer-reviewed findings, funding ties, open admission that they shape their analyses to serve purposes of litigation and other methodological challenges have sparked controversies, with critics questioning the robustness and impartiality of its conclusions (Felke J. 2024). Despite these issues, WWA's work continues to shape climate science and media narratives. Technical criticisms of the approach include: neglect of a formal detection process; an implicit assumption that 100% of the post-industrial warming is caused by CO₂; and failure to adequately account for natural internal climate variability.

Because EEA is relatively new many basic methodological issues have yet to be settled in the expert literature. An important challenge is the lack of data. Extreme events are by definition rare. Many analyses of extreme event types (including the US National Assessment Reports) only evaluate data since 1950 or 1970. However, as emphasized by Chapter 8, many of the worst extreme weather and climate events in U.S. history occurred prior to the first half of the 20th century including in the early 19th century. And if paleoclimate reconstructions are considered, it becomes very difficult for an event to pass the detection thresholds of exceeding what is expected from natural variability, particularly if a reasonably sized geographic region is considered.

Another challenge is defining the event under study. There is a longstanding literature in statistics and econometrics on the challenge of analyzing data with outliers. The issue arises because a data series establishes a probability distribution defining the expected range of observations. If an outlier is observed it might indicate that the underlying process giving rise to the data distribution has changed (which in the weather context would mean a climatic change has been detected) or that the underlying process has multiple regimes each with a different probability distribution, in which case observing an outlier simply means we were temporarily in a different regime, but the system itself was unchanged. If a time series contains only a single outlier event at the end of the series it is not possible to determine which model is the correct one (Chen and Liu 1993). For instance, there might be an "ordinary" weather regime that yields a distribution of summer daytime highs in a particular coastal region, and a second "heatwave" regime that kicks in when an inland blocking event occurs, which yields a temperature distribution centered 15°C higher than the first one. A day with temperatures 13°C above normal would either be an extreme heat anomaly under the first regime or a somewhat cool event under the second, and we have no way in this case of knowing on statistical grounds which view is correct.

Visser and Petersen (2012) and Sardeshmukh et al. (2015) both point out that different distributions may fit observed data equally well but yield very different implications about the likelihood of a specific weather event. Visser and Petersen argue that, in view of the deep uncertainties of extreme weather analysis drawing a connection between individual events and global climate change should be avoided. Furthermore the existence of an outlier at the end of a data series poses the problem that estimates of the event probabilities will be biased whether the outlier is included or excluded (Barlow et al. 2020). Methods to eliminate the bias have not yet been established, leading some experts (eg. Miralles and Davison 2023) to argue that in settings in which a data series contains a single extreme event at the end, estimation of a return period for the extreme event will be so biased and uncertain it should be avoided altogether.

In spite of these concerns, the U.S. is presently considering something like the WWA, which is being investigated by a NASEM Panel on Attribution of Extreme Weather and Climate Events and their impacts (NASEM, 2025).

A case studies from a recent high impact extreme events in the U.S. is provided to illustrate the challenges and ambiguities in attributing the frequency and intensity of extreme weather events to human-caused warming.

7.6. Case study – 2021 Western North America heat wave

The 2021 Western North America heat wave was an extreme heat wave that affected much of Western North America in late June 2021. In particular, surface temperature records were set in Portland, OR (116°F; previous record 107°F) and Seattle, WA (108 °F; previous record 103°F) (Mass et al., 2024).

The WWA team garnered international headlines for their analysis and provided the following attribution statements (WWA, 2021; Philip et al., 2022):

Based on observations and modeling, the occurrence of this heatwave was virtually impossible without human-caused climate change.

The event is estimated to be about a 1 in 1000-year event in today's climate.

The event would have been at least 150 times rarer without human-induced climate change.

This heatwave was about 2°C hotter than it would have been if it had occurred at the beginning of the industrial revolution (when global mean temperatures were 12°C cooler than today).

But an important caveat to the first claim is that other researchers concluded, based on historical weather data, that while a heat wave of the magnitude observed was indeed virtually impossible without anthropogenic climate change, it was also virtually impossible *with* climate change. Bercos-Hickey (2022) noted “these temperatures were virtually impossible under any previously experienced meteorological conditions, with or without global warming.” McKinnon and Simpson (2022) stated “the most likely explanation remains that the weather event itself was ‘bad luck.’” The 2023 Oregon Climate Assessment (Fleischman 2023) concluded that the

heat dome would have formed even without climate change and “There is no evidence that the highly unusual combination of weather features that drove the heat dome were made more likely by climate change, and climate models do not project an increase in the frequency of high-pressure ridges over the Pacific Northwest” (Fleischman 2023 p. 49).

Mass et al. (2024) summarizes the proximate sequence of compound events leading to the heat wave. There was a record-breaking midtropospheric ridge over the Pacific Northwest, forced by a tropical disturbance in the western Pacific. This produced record-breaking midtropospheric temperatures, strong subsidence in the lower atmosphere, low-level easterly flow that produced downslope warming on regional terrain and the removal of cooler marine air, and an approaching low-level trough that enhanced downslope flow. The event occurred at a time of maximum solar insolation, and drier-than-normal soil moisture. Using a storyline approach, Mass et al. assessed that there is no trend in drought and dry soils in the Pacific Northwest; there is no evidence of global warming producing stronger ridges of high pressure, and no observed trend in heat waves or record temperatures in the region. They concluded that although anthropogenic warming may have contributed as much as 2°F to the magnitude of the event, there is little evidence of further amplification of the event from increasing greenhouse gases.

A statistical analysis of a model-based attribution study of this heat wave was conducted by Bercos-Hickey et al. (2022). Because this event is a far outlier and far above the bounds of Generalized Extreme Value distributions fitted from historical data, they concluded that estimates of return times, quantitative changes in event magnitude and frequency, and probability of the extreme temperatures such as provided by the WWA are not accurate and should be interpreted as having low confidence. They found that hindcast attribution methods using an ensemble of regional climate models, combined with Pearl (2009) causal inferences, can provide limited and conditional information about the magnitude of the human influence on this heatwave – they provided a more highly constrained estimate that human activities caused a ~1.4°C–1.8°F increase in the daily maximum temperatures.

Zeder et al. (2023) also concluded that the methods employed by Philip et al. (2022) tend to overstate the rarity of extreme heat waves, leading to a biased perception of the effect of climate change on the heatwave event: “The tendency to overestimate the return period of observed extreme heatwave events may fuel the impression that seemingly impossible heatwave extremes are currently clustering at an unprecedented rate.”

The 2021 Western North America heatwave was a rare and unprecedented compound weather event, that broke century-old temperature records by as much as 9°F. While the WWA team received worldwide publicity for their rapid attribution claims blaming anthropogenic climate change, subsequent peer-reviewed analysis showed that the rare event was not made more probable by global warming.

7.7. Summary

There is an ongoing scientific debate around attribution methods, particularly in attributing extreme weather events to climate change. The IPCC has long cautioned that methods to

establish causality in climate science are inherently uncertain and ultimately depend on expert judgement.

There are two areas of substantive criticism of the IPCC assessment of the causes of the recent warming: inadequate assessment of natural climate variability, and inappropriate statistical methods.

Detection of extreme weather events is challenged by their rarity, requiring a long data set and a choice of region and spatial scale to evaluate their occurrence against the background of natural weather and climate variability.

The most robust attribution statements for an extreme event relate to an incremental change (e.g. a temperature change in degrees or percent change in rainfall). Statements related to return times,

quantitative changes in event magnitude and frequency, and probability of the extremes are not accurate owing to an inadequate amount of data, and are made with low confidence. There is no evidence in a change of weather or climate regime patterns from increasing greenhouse gases that would amplify or dampen extreme weather events, beyond basic thermodynamic considerations.

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8. Extreme weather in the US and elsewhere

8.1. Introduction

Weather extremes, usually related to temperature and/or precipitation, can disrupt infrastructure and therefore endanger human health and wellbeing. The issue is not whether extremes occur, for they are intrinsic to the chaotic climate system. Rather, it is whether there are long-term (decadal scale) changes in the frequency or character of extremes ("detection"), as well as the extent to which such changes and the attendant changes in hazards are caused by anthropogenic emissions of greenhouse gases ("attribution"; e.g., IPCC AR6 Seneviratne et al 2021).

It is naïve to assume that any recent unprecedented extreme event is caused by human influences on the climate. That assumption is wrong in two ways. First, climate is about the statistical properties of weather over decades, not single events. And second, there are only about 130 years of reliable observational records that can be analyzed statistically. That brief interval does not begin to contain all of the extreme events that the climate system can create on its own. Over geologic time the climate system has generated an (essentially) infinite variety of weather patterns and extremes that humans have never observed, and thus are absent from the databases used to determine extreme statistics.³ [see *Perils of short data records* below]. For that reason, attributing an extreme event unprecedented in the record requires assumptions about the magnitude of natural variations.

This is especially true for precipitation events. The hydrological literature has long noted the phenomenon of *Long Term Persistence* (LTP) in rainfall data (Hurst 1951, Cohn and Lins 2005, Markonis and Koutsoyiannis 2015). LTP has a formal mathematical definition but it can be thought of intuitively as the presence of natural variations with strong autocorrelation properties that result in cycle-like behavior on long time scales. The presence of LTP requires long records to accurately estimate variability. Analysis of records short relative to the LTP scale will tend to underestimate variability, therefore overstating the significance of apparent trends and underestimating the likelihood of extreme events (Cohn and Lins 2005).

A good example of LTP is the eight-century long record of the annual minimum height of the Nile River observed at Roda Island in Cairo (shown below) in Figure 8.1.1. Since human influences on the global climate were negligible before the 20th century, the century-scale variability of the thirty-year average is entirely natural; Egyptians of the seventh and eight centuries would have been incorrect to assume that the worsening drought during that time was the "new normal."

Commented [A6]: Need to get a good citation for these data

³ For example, under the simplest statistical assumptions there is a 37 percent chance that a 100-year event is NOT present in a century-long record.

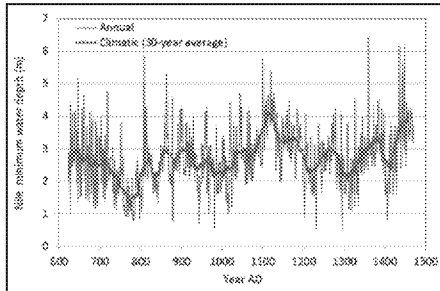


Figure 8.1.1: Ne River discharge [details, source]

With these caveats in mind we examine the evidence for changes in selected weather and climate extremes. It has become routine in media discussions, government and private sector discussions and even in some academic literature to make generalized assertions that extreme weather of all types is getting worse due to GHGs and climate change. Yet expert assessments have not typically drawn such sweeping conclusions and instead have emphasized the difficulty both of identifying specific trends and establishing a causal connection with anthropogenic forcing. For the benefit of readers who may not have read the relevant reports we will begin with extended excerpts of findings from previous IPCC and NCA assessments, then in the remainder of this chapter survey additional data relevant to US and global extreme weather trends.

8.2. Review of IPCC and NCA Findings on Extreme Weather

The sources we review will be denoted as follows:

SREX: The IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (2012)

AR5: The IPCC Fifth Assessment Report Working Group 1 (2013).

AR6: The IPCC Sixth Assessment Report Working Group 1 (2021).

NCA17: The US Climate Science Special Report of the Fourth National Climate Assessment (2017) Volume I Chapter 6.

8.2.1 Overview: IPCC Assessment of signal emergence in extreme weather types

(AR6 WG1 Table 12.12)

Climate Impact Driver Type	Climate Impact Driver Category	Already Emerged in the Historical Record?	Emerging by 2050 in Most Extreme CO2 Emissions Scenario?	Emerging by 2100 in Most Extreme CO2 Emissions Scenario?
Heat & Cold	Average air temperature	YES in most regions	YES	YES
	More heat extremes	YES in most regions	YES in land regions	YES
	Fewer cold extremes	YES in a few regions	YES in many regions	YES
	Less frost	NO	NO	NO
Wet & Dry	Average Precip. (Increase or Decrease)	NO	YES (incr) YES (decr)	YES (incr) YES (decr)
	River flooding	NO	NO	NO
	Heavy precip & pluvial flood	NO	NO	YES in a few regions
	Landslide	NO	NO	NO
	Aridity	NO	NO	NO
	Hydrologic Drought	NO	NO	NO
	Agricultural & ecological drought	NO	NO	NO
	Fire weather	NO	NO	NO
Wind	Average wind speed	NO	NO	NO
	Severe wind storm	NO	NO	NO
	Tropical cyclone	NO	NO	NO
	Sand and dust storm	NO	NO	NO
Snow and Ice	Snow, glacier & ice sheet	NO	YES in a few regions	YES Arctic snow
	Permafrost	YES	YES	YES
	Lake & river ice	NO	YES	YES
	Arctic sea ice	YES	YES	YES
	Antarctic sea ice	NO	YES	YES

	Heavy snow fall and ice storm	NO	NO	NO
	Hail	NO	NO	NO
	Snow avalanche	NO	NO	NO
Coastal	Relative sea level	NO	YES	YES
	Coastal flood	NO	NO	NO
	Coastal erosion	NO	NO	NO
Open Ocean	Average ocean temperature	YES	YES	YES
	Marine heat wave	NO	NO	NO
	Ocean acidity	NO	YES	YES
	Ocean salinity	YES	YES	YES
	Dissolved oxygen	YES (Pacific & S. Ocean)	YES	YES
Other	Air pollution weather	NO	NO	NO
	Solar or IR radiation at surface	NO	NO	NO

Table 8.21. IPCC AR6 summary of the probable emergence of an anthropogenic signal above natural climate variability for all global or regional “climate impact drivers” (CIDs) of concern for humans and ecosystems in response to increasing atmospheric greenhouse gas concentrations (primarily CO₂). Source: Table adapted from report of Working Group I, Table 12.12). Red = high confidence; yellow = medium confidence; green = no anthropogenic signal detectable above natural variability (50% confidence).

Table 8.21 reproduces the findings of AR6 Table 12.12 which indicates, for 34 major weather event and impact types, whether a signal of anthropogenic forcing has been detected in the historical record (column 1), whether such a signal is likely to emerge by 2050 under the extreme RCP8.5 scenario (column 2) and whether it is likely to emerge by 2100 under RCP8.5 forcing (column 3). It should be borne in mind that the latter two columns suffer from the deficiencies of GCMs discussed in Chapter XX. And as we discussed in Ch X on attribution, AR6 offers conflicting messages about attribution of extreme weather. Nevertheless, we provide this Table for reference.

Several patterns stand out. First, detection of an anthropogenic signal is asserted with *high confidence* in only four of the 34 weather impact categories, and with *medium confidence* in a further four. The IPCC does NOT claim to have detected an anthropogenic signal in the remaining 26 categories. Of the four *high confidence* assertions, two are for changes in average

temperatures (air and ocean), which are not measures of extreme weather. Further, two of the four *medium confidence* assertions are related to ocean chemistry and also not related to extreme weather. The IPCC does NOT assert a detectable human influence on many non-temperature weather features such as wind, precipitation, flooding, and drought.

Second, columns 2 and 3 show that the IPCC expects very few anthropogenic trends to emerge within this century, *even under the most extreme forcing scenario*. As we discuss in Section 4.2 the RCP8.5 scenario is an implausible high-end storyline, not a “base case” or “business-as-usual” projection. Even so, most weather impacts are not expected to show an anthropogenic signal this century. Natural variability dominates patterns of extreme weather systems and simplistic assertions of trend detection are frequently undermined by regional heterogeneity and trend reversals over time.

Taking wind as an example, the IPCC claims that an anthropogenic signal has NOT emerged in average wind speeds, severe windstorms, tropical cyclones, or sand and dust storms, and none are expected to emerge this century even under an extreme emissions scenario. The same applies to drought and fire weather. This table alone suffices to illustrate the gap between IPCC expert assessments of extreme weather and discussions in the popular media and political arenas. As we show below the Table reflects longstanding conclusions of the IPCC and other assessment bodies. In the next few sections we will simply present without comment excerpts from past assessment reports.⁴ In selecting these excerpts, we’ve focused on the highest-level summaries to avoid accusations of bias through “cherry picking”.

⁴ In these excerpts we have added **bold-face** emphasis, while *italicized* emphasis on confidence terms appears in the original sources. Citations in quoted text can be found in the underlying reports but are not reproduced here.

8.2.2 Flooding

SREX (p. 176)

In the United States and Canada during the 20th century and in the early 21st century, there is no compelling evidence for climate-driven changes in the magnitude or frequency of floods.

AR5 (p. 214)

AR4 WGI Chapter 3 (Trenberth et al., 2007) did not assess changes in floods but AR4 WGI concluded that **there was not a general global trend in the incidence of floods** (Kundzewicz et al., 2007). SREX went further to suggest that there was low agreement and thus *low confidence* at the global scale regarding changes in the magnitude or frequency of floods or even the sign of changes.

AR5 WGI assesses floods in regional detail accounting for the fact that trends in floods are strongly influenced by changes in river management (see also Section 2.5.2). Although the most evident flood trends appear to be in northern high latitudes, where observed warming trends have been largest, in some regions no evidence of a trend in extreme flooding has been found, for example, over Russia based on daily river discharge (Shklomanov et al., 2007). Other studies for Europe (Hannaford and Marsh, 2008; Renard et al., 2008; Petrow and Merz, 2009; Stahl et al., 2010) and Asia (Jiang et al., 2008; Delgado et al., 2010) show evidence for upward, downward or no trend in the magnitude and frequency of floods, so that there is currently no clear and widespread evidence for observed changes in flooding except for the earlier spring flow in snow-dominated regions (Seneviratne et al., 2012).

In summary, there continues to be a lack of evidence and thus *low confidence* regarding the sign of trend in the magnitude and/or frequency of floods on a global scale.

AR6 (Ch 11 p. 1568)

The SREX (Seneviratne et al., 2012) assessed *low confidence* for observed changes in the magnitude or frequency of floods at the global scale. This assessment was confirmed by the AR5 report (Hartmann et al., 2013). The SR15 (Hoegh-Guldberg et al., 2018) found increases in flood frequency and extreme streamflow in some regions, but decreases in other regions. **While the number of studies on flood trends has increased since the AR5 report, and there were also new analyses after the release of SR15 (Berghuijs et al., 2017; Blöschl et al., 2019; Gudmundsson et al., 2019), hydrological literature on observed flood changes is heterogeneous, focusing at regional and sub-regional basin scales, making it difficult to synthesise at the global and sometimes regional scales.**

In summary, the seasonality of floods has changed in cold regions where snowmelt dominates the flow regime in response to warming (*high confidence*). **Confidence about peak flow trends**

over past decades on the global scale is *low*, but there are regions experiencing **increases**, including parts of Asia, southern South America, the northeast USA, northwestern Europe, and the Amazon, **and regions experiencing decreases**, including parts of the Mediterranean, Australia, Africa, and the southwestern USA.

US NCA17 pp. 240-41:

"The IPCC AR5 did not attribute changes in flooding to anthropogenic influence nor report detectable changes in flooding magnitude, duration, or frequency. Trends in extreme high values of streamflow are mixed across the United States. Analysis of 200 U.S. stream gauges indicates areas of both increasing and decreasing flooding magnitude but does not provide robust evidence that these trends are attributable to human influences...

The complex mix of processes complicates the formal attribution of observed flooding trends to anthropogenic climate change and suggests that additional scientific rigor is needed in flood attribution studies. As noted above, precipitation increases have been found to strongly influence changes in flood statistics. However, in U.S. regions, **no formal attribution of precipitation changes to anthropogenic forcing has been made so far, so indirect attribution of flooding changes is not possible. Hence, no formal attribution of observed flooding changes to anthropogenic forcing has been claimed."**

8.23 Heatwaves

AR5 (p. 212 WG1)

Table 2.13 shows that there has been a *likely* increasing trend in the frequency of heatwaves since the middle of the 20th century in Europe and Australia and across much of Asia where there are sufficient data. However, confidence on a global scale is *medium* owing to lack of studies over Africa and South America but also in part owing to differences in trends depending on how heatwaves are defined (Perkins et al., 2012). Using monthly means as a proxy for heatwaves Coumou et al. (2013) and Hansen et al. (2012) indicate that record-breaking temperatures in recent decades substantially exceed what would be expected by chance but caution is required when making inferences between these studies and those that deal with multi-day events and/ or use more complex definitions for heatwave events. **There is also evidence in some regions that periods prior to the 1950s had more heatwaves (e.g., over the USA, the decade of the 1930s stands out and is also associated with extreme drought conditions** (Peterson et al., 2013) whereas conversely in other regions heatwave trends may have been underestimated owing to poor quality and/or consistency of data (e.g., Della-Marta et al. (2007a) over Western Europe; Kugitsch et al. (2009, 2010) over the Mediterranean). Recent available studies also suggest that the number of cdd spells has reduced significantly since the 1950s (Donat et al., 2013a, 2013c).

In summary, new analyses continue to support the AR4 and SREX conclusions that since about 1950 it is very *likely* that the numbers of cold days and nights have decreased and the numbers

of warm days and nights have increased overall on the global scale, that is, for land areas with sufficient data. It is *likely* that such changes have also occurred across most of North America, Europe, Asia and Australia.

NCA17 (pp. 190-191)

Changes in warm extremes are more nuanced than changes in cold extremes. For instance, the warmest daily temperature of the year increased in some parts of the West over the past century (Figure 6.3), but there were decreases in almost all locations east of the Rocky Mountains. In fact, all eastern regions experienced a net decrease (Table 6.2), most notably the Midwest (about 2.2°F [1.2°C]) and the Southeast (roughly 1.5°F [0.8°C]). The decreases in the eastern half of [the] Nation, particularly in the Great Plains, are mainly tied to the unprecedented summer heat of the 1930s Dust Bowl era, which was exacerbated by land-surface feedbacks driven by springtime precipitation deficits and land mismanagement. However, anthropogenic aerosol forcing may also have reduced summer temperatures in the Northeast and Southeast from the early 1950s to the mid-1970s, and agricultural intensification may have suppressed the hottest extremes in the Midwest.

Since the mid-1960s, there has been only a very slight increase in the warmest daily temperature of the year (amidst large interannual variability). **Heat waves (6-day periods with a maximum temperature above the 90th percentile for 1961–1990) increased in frequency until the mid-1930s, became considerably less common through the mid-1960s, and increased in frequency again thereafter (Figure 6.4). As with warm daily temperatures, heat wave magnitude reached a maximum in the 1930s.**

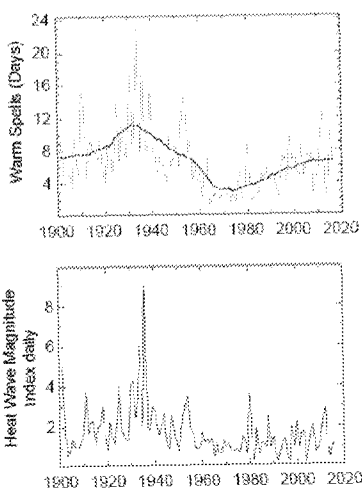


Figure 8.21: US Heat waves since 1900. Source: NCA17 Figure 6.4

AR6 (p. 1550)

In North America (Table 11.19), there is very robust evidence for a *very likely* increase in the intensity and frequency of hot extremes and decrease in the intensity and frequency of cold extremes for the whole continent, though there are substantial spatial and seasonal variations in the trends. Minimum temperatures display warming consistently across the continent, **while there are more contrasting trends in the annual maximum daily temperatures** in parts of the USA (Figure 11.9; Lee et al, 2014; van Oldenborgh et al, 2019; Dunn et al., 2020).

8.24 Extreme snowfall events

Note: extreme snowfall events in the US northeast are assessed in relation to winter Extratropical Cyclone (ETC) activity.

AR6 Ch 11. p. 1593

There is *high confidence* that snowfall associated with winter ETCs will decrease in the future, because increases in tropospheric temperatures lead to a lower proportion of precipitation falling as snow (O’Gorman, 2014; Rhoades et al, 2018; Zarzycki, 2018). However, there is *medium confidence* that extreme snowfall events associated with winter ETCs will change little in regions where snowfall will be supported in the future (O’Gorman, 2014; Zarzycki, 2018).

8.25 Extreme precipitation

SREX (p. 142)

Recent studies have updated the assessment of the AR4, with more regional results now available (Table 3-2). Overall, this additional evidence confirms that **more locations and studies show an increase than a decrease in extreme precipitation, but that there are also wide regional and seasonal variations**, and trends in many regions are not statistically significant (Table 3-2)... Based on station data from Canada, the United States, and Mexico, Peterson et al (2008a) reported that heavy precipitation has been increasing over 1950-2004, as well as the average amount of precipitation falling on days with precipitation.

AR5 (pp. 213-14)

In summary, further analyses continue to support the AR4 and SREX conclusions that it is *likely* that since 1951 there have been statistically significant increases in the number of heavy precipitation events (e.g., above the 95th percentile) in more regions than there have been statistically significant decreases, but there are strong regional and subregional variations in the

trends. In particular, many regions present statistically non-significant or negative trends, and, where seasonal changes have been assessed, there are also variations between seasons (e.g., more consistent trends in winter than in summer in Europe). The overall most consistent trends towards heavier precipitation events are found in central North America (very likely increase) but assessment for Europe shows likely increases in more regions than decreases.

AR6 (p. 1560)

In North America, there is robust evidence that the magnitude and intensity of extreme precipitation has *very likely* increased since the 1950s. Both [one-day maxima] and [5-day maxima] have significantly increased in North America during 1950-2018 (Sun et al., 2020, also Figure 11.13). There is, however, regional diversity. In Canada, there is a lack of detectable trends in observed annual maximum daily (or shorter duration) precipitation (Shephard et al., 2014; Mekis et al., 2015; Vincent et al., 2018).

NCA17 pp. 213-14:

Detectability of trends (compared to internal variability) for a number of precipitation metrics over the continental United States has been examined; **however, trends identified for the U.S. regions have not been clearly attributed to anthropogenic forcing.** One study concluded that increasing precipitation trends in some north-central U.S. regions and the extreme annual anomalies there in 2013 were at least partly attributable to the combination of anthropogenic and natural forcing... **Based on current evidence, it is concluded that detectable but not attributable increases in mean precipitation have occurred over parts of the central United States.** Formal detection-attribution studies indicate a human contribution to extreme precipitation increases over the continental United States, but confidence is *low* based on those studies alone due to the short observational period, high natural variability, and model uncertainty.

In summary, based on available studies, it is concluded that for the continental United States there is *high confidence* in the detection of extreme precipitation increases, while there is *low confidence* in attributing the extreme precipitation changes purely to anthropogenic forcing.

8.26 Tornadoes and severe convective storms

IPCC AR6 Sct. 11.7.3, p. 1594

Severe convective storms are convective systems that are associated with extreme phenomena such as tornadoes, hail, heavy precipitation (rain or snow), strong winds, and lightning.

The assessment of changes in severe convective storms in SREX (Chapter 3, Seneviratne et al., 2012) and AR5 (Chapter 12, Collins et al., 2013) is limited and focused mainly on tornadoes and hail storms. The SREX assessed that **there is *low confidence* in observed trends in**

tornadoes and hail because of data inhomogeneities and inadequacies in monitoring systems. Subsequent literature assessed in the Climate Science Special Report (Kossin et al., 2017) led to the assessment of the observed tornado activity over the 2000s in the USA, with a decrease in the number of days per year with tornadoes and an increase in the number of tornadoes on these days (*medium confidence*). However, **there is *low confidence* in past trends for hail and severe thunderstorm winds**. Climate models consistently project environmental changes that would support an increase in the frequency and intensity of severe thunderstorms that combine tornadoes, hail, and winds (*high confidence*), but there is *low confidence* in the details of the projected increase.

... In summary, because the definition of severe convective storms varies depending on the literature and the region, it is not straightforward to make a synthesizing view of observed trends in severe convective storms in different regions. In particular, **observational trends in tornadoes, hail, and lightning associated with severe convective storms are not robustly detected** due to insufficient coverage of the long-term observations. There is *medium confidence* that the mean annual number of tornadoes in the USA has remained relatively constant, but their variability of occurrence has increased since the 1970s, particularly over the 2000s, with **a decrease in the number of days per year, and an increase in the number of tornadoes on these days** (*high confidence*). Detected tornadoes have also increased in Europe, but the trend depends on the density of observations.

... In summary, **it is extremely difficult to detect and attribute changes in severe convective storms**. There is limited evidence that extreme precipitation associated with severe convective storms has increased in some cases.

8.2.7 Hurricanes and Tropical Cyclones

SREX (p. 159):

There have been no significant trends observed in global tropical cyclone frequency records, including over the present 40-year period of satellite observations (e.g., Webster et al., 2005). Regional trends in tropical cyclone frequency have been identified in the North Atlantic, but the fidelity of these trends is debated (Holland and Webster, 2007; Landsea, 2007; Mann et al., 2007a). Different methods for estimating undercounts in the earlier part of the North Atlantic tropical cyclone record provide mixed conclusions (Chang and Guo, 2007; Mann et al., 2007b; Kunkel et al., 2008; Vecchi and Knutson, 2008). Regional trends have not been detected in other oceans (Chan and Xu, 2009; Kubota and Chan, 2009; Callaghan and Power, 2011). It thus remains uncertain whether any observed increases in tropical cyclone frequency on time scales longer than about 40 years are robust, after accounting for past changes in observing capabilities (Knutson et al., 2010).

AR5 (pp. 216-17):

Current data sets indicate no significant observed trends in global tropical cyclone frequency over the past century and it remains uncertain whether any reported long-term increases in tropical cyclone frequency are robust, after accounting for past changes in observing capabilities (Knutson et al., 2010). **No robust trends in annual numbers of tropical storms, hurricanes and major hurricanes counts have been identified** over the past 100 years in the North Atlantic basin. Measures of land-falling tropical cyclone frequency (Figure 2.34) are generally considered to be more reliable than counts of all storms which tend to be strongly influenced by those that are weak and/or short lived. Callaghan and Power (2011) find a statistically significant decrease in Eastern Australia land-falling tropical cyclones since the late 19th century although including 2010/2011 season data this trend becomes non-significant (i.e., a trend of zero lies just inside the 90% confidence interval). Significant trends are not found in other oceans on shorter time scales (Chan and Xu, 2009; Kubota and Chan, 2009; Mohapatra et al., 2011; Weinkle et al., 2012), although Grinsted et al. (2012) find a significant positive trend in eastern USA using tide-gauge data from 1923–2008 as a proxy for storm surges associated with land-falling hurricanes. Differences between tropical cyclone studies highlight the challenges that still lie ahead in assessing long-term trends.

In summary, this assessment does not revise the SREX conclusion of *low confidence* that any reported long-term (centennial) increases in tropical cyclone activity are robust, after accounting for past changes in observing capabilities. More recent assessments indicate that **it is unlikely that annual numbers of tropical storms, hurricanes and major hurricanes counts have increased over the past 100 years in the North Atlantic basin**. Evidence, however, is for a virtually certain increase in the frequency and intensity of the strongest tropical cyclones since the 1970s in that region.

AR6 (p. 1585)

There is *low confidence* in most reported long-term (multidecadal to centennial) trends in TC frequency- or intensity-based metrics due to changes in the technology used to collect the best-track data. This should not be interpreted as implying that no physical (real) trends exist, but rather as indicating that either the quality or the temporal length of the data is not adequate to provide robust trend detection statements, particularly in the presence of multidecadal variability.

There are previous and ongoing efforts to homogenize the best-track data (Esner et al., 2008; Kossin et al., 2013, 2020; Choy et al., 2015; Landsea, 2015; Emanuel et al., 2018) and there is substantial literature that finds positive trends in intensity-related metrics in the best-track during the “satellite period”, which is generally limited to the past ~40 years (Kang and Esner, 2012; Kishitawala et al., 2012; Kossin et al., 2013, 2020; Mei and Xie, 2016; Zhao et al., 2018; Tauvale and Tsuboki, 2019). **When best-track trends are tested using homogenized data, the intensity trends generally remain positive, but are smaller in amplitude** (Kossin et al., 2013; Holland and Bruyère, 2014). **Kossin et al. (2020) extended the homogenized TC intensity record to the period 1979–2017 and identified significant global increases in**

major TC exceedance probability of about 6% per decade.⁵ In addition to trends in TC intensity, there is evidence that TC intensification rates and the frequency of rapid intensification events have increased within the satellite era (Kishlawal et al. 2012; Balaguru et al., 2018; Bhatia et al., 2018). The increase in intensification rates is found in the best-track as well as the homogenized intensity data.

A subset of the best-track data corresponding to hurricanes that have directly impacted the United States since 1900 is considered to be reliable, and shows no trend in the frequency of U.S. landfall events (Knutson et al., 2019).

8.28 Droughts

US NCA17 REPORT (Ch. 8, Wehner et al. 2017)

p. 231:

Recent droughts and associated heat waves have reached record intensity in some regions of the United States; however, by geographical scale and duration, the Dust Bowl era of the 1930s remains the benchmark drought and extreme heat event in the historical record (very high confidence). **While by some measures drought has decreased over much of the continental United States in association with long-term increases in precipitation, neither the precipitation increases nor inferred drought decreases have been confidently attributed to anthropogenic forcing.**

The human effect on recent major U.S. droughts is complicated. Little evidence is found for a human influence on observed precipitation deficits, but much evidence is found for a human influence on surface soil moisture deficits due to increased evapotranspiration caused by higher temperatures. (*High confidence*)

p. 233:

Drought is, of course, directly connected to seasonal precipitation totals. Figure 7.1 shows detectable observed recent changes in seasonal precipitation. In fact, the

⁵ The **underlined** text referenced a study (Kossin et al. 2020) that later retracted a portion of its findings. Those authors assembled a data set on global TC incidence spanning 1979 to 2017 from which they claimed that the global fraction of TCs reaching major status (Cat 3–5) rose from 27% during 1979–1997 to 31% during 1998–2017 and that the increase was statistically significant. However, closer examination of their results showed a significant increase only in the North Atlantic (18% to 34%) whereas changes in all other basins (Eastern Pacific, Western Pacific, North Indian, South Indian, South Pacific) were not statistically significant. In a subsequent correction ([HYPERLINK "<https://www.pnas.org/doi/10.1073/pnas.2021573117>"]), Kossin et al. stated that the global probability of observing a major TC rose from 34% during 1979–1997 to 37% in the later period and that the evidence for statistical significance was now weaker. Nevertheless, the authors claimed that the correction did not affect their conclusions.

increases in observed summer and fall precipitation are at odds with the projections in Figure 7.5. **As a consequence of this increased precipitation, drought statistics over the entire CONUS have declined.**

SREX (p. 170)

From a paleoclimate perspective recent droughts are not unprecedented, with severe 'megadroughts' reported in the paleoclimatic record for Europe, North America, and Australia (Jansen et al., 2007). Recent studies extend this observation to African and Indian droughts (Sirha et al., 2007; Shanahan et al., 2009): much more severe and longer droughts occurred in the past centuries with widespread ecological, political, and socioeconomic consequences. Overall, these studies confirm that in the last millennium several extreme droughts have occurred (Breda and Badeau, 2008; Kallis, 2008; Büntgen et al., 2010).

In North America, there is *medium confidence* that there has been an overall slight tendency toward less dryness (wetting trend with more soil moisture and runoff; Table 3-2), although analyses for some subregions also indicate tendencies toward increasing dryness. This assessment is based on several lines of evidence, including simulations with different hydrological models as well as PDSI and CDD estimates (Alexander et al., 2006; Andreadis and Lettenmaier, 2006; van der Schrier et al., 2006a; Kunkel et al., 2008; Sheffield and Wood, 2008a; Dai, 2011).

The most severe droughts in the 20th century have occurred in the 1930s and 1950s, where the 1930s Dust Bowl was most intense and the 1950s drought most persistent (Andreadis et al., 2005) in the United States, while in Mexico the 1950s and late 1990s were the driest periods. Recent regional trends toward more severe drought conditions were identified over southern and western Canada, Alaska, and Mexico, with subregional exceptions (Dai, 2011).

SREX (p. 172)

Overall, though new studies have furthered the understanding of the mechanisms leading to drought, there is still relatively limited evidence to provide an attribution of observed changes, in particular given the issues associated with the availability of observational data (Section 3.2.1) and the definition and computation of drought indicators (Box 3-3). This latter point was mostly identified in post-AR4 studies (Box 3-3). Moreover, regions where consistent increases in drought are identified (see 'Observed Changes') are only partly consistent with those where projections indicate an enhancement of drought conditions in coming decades (see next paragraphs). We thus assess that there is *medium confidence* (see also Section 3.1.5) that anthropogenic influence has contributed to some changes in the drought patterns observed in the second half of the 20th century, based on its attributed impact on precipitation and temperature changes (though temperature can only be indirectly related to drought trends; see Box 3-3). However there is *low confidence* in the attribution of changes in droughts at the level of individual regions.

AR5 (pp. 214-215)

Based on evidence since AR4, SREX concluded that there were not enough direct observations of dryness to suggest high confidence in observed trends globally, although there was *medium confidence* that since the 1950s some regions of the world have experienced more intense and longer droughts. The differences between AR4 and SREX are due primarily to analyses post-AR4, differences in how both assessments considered drought and updated IPCC uncertainty guidance.

Because drought is a complex variable and can at best be incompletely represented by commonly used drought indices, discrepancies in the interpretation of changes can result. For example, Sheffield and Wood (2008) found decreasing trends in the duration, intensity and severity of drought globally. Conversely, Dai (2011a,b) found a general global increase in drought, although with substantial regional variation and individual events dominating trend signatures in some regions (e.g., the 1970s prolonged Sahel drought and the 1930s drought in the USA and Canadian Prairies). Studies subsequent to these continue to provide somewhat different conclusions on trends in global droughts and/or dryness since the middle of the 20th century (Sheffield et al., 2012; Dai, 2013; Donat et al., 2013c; van der Schrier et al., 2013).

In summary, the current assessment concludes that there is not enough evidence at present to suggest more than *low confidence* in a global-scale observed trend in drought or dryness (lack of rainfall) since the middle of the 20th century, owing to lack of direct observations, geographical inconsistencies in the trends, and dependencies of inferred trends on the index choice. Based on updated studies, AR4 conclusions regarding global increasing trends in drought since the 1970s were probably overstated. However, it is *likely* that the frequency and intensity of drought has increased in the Mediterranean and West Africa and decreased in central North America and north-west Australia since 1950.

AR6 (Drought, Observed trends, Section 11.6.2 pp. 1573-75)

p. 1573

Strong precipitation deficits have been recorded in recent decades in the Amazon (2005, 2010), south-western China (2009–2010), south-western North America (2011–2014), Australia (1997–2009), California (2014), the middle East (2012–2016), Chile (2010–2015), the Great Horn of Africa (2011), among others (van Dijk et al., 2013; Mann and Gleick, 2015; Rowel et al., 2015; Marengo and Espinoza, 2016; Dai and Zhao, 2017; Garreaud et al., 2017, 2020; Marengo et al., 2017; Brito et al., 2018; Cook et al., 2018). **Global studies generally show no significant trends in SPI time series** (Orlowsky and Seneviratne, 2013; Spinoni et al., 2014), **and in derived drought frequency and severity data** (Spinoni et al., 2019), with very few regional exceptions (Section 11.9 and Figure 11.17).

p. 1574

For AR6 regions, several studies suggest an increase in the frequency and areal extent of soil moisture deficits, with examples in East Asia (Cheng et al., 2015; Y. Qin et al., 2015; Jia et al., 2018), Western and Central Europe (Trnka et al., 2015b), and the Mediterranean (Harel et al., 2018; Mbravec et al., 2019; Markonis et al., 2021). **Nonetheless, some analyses also show no long-term trends in soil drying in some AR6 regions – for example, in Eastern North America (Park Williams et al., 2017) and Central North America (Seager et al., 2019), as well as in North Eastern Africa (Kew et al., 2021).**

There is evidence based on streamflow records of increased hydrological droughts in East Asia (D. Zhang et al., 2018) and southern Africa (Gudmundsson et al., 2019). **In areas of Western and Central Europe and Northern Europe, there is no evidence of changes in the severity of hydrological droughts since 1950** based on flow reconstructions (Caillouet et al., 2017; Barker et al., 2019) and observations (Vicente-Serrano et al., 2019). **In North America, depending on the methods, datasets and study periods, there are differences between studies that suggest an increase (Shukla et al., 2015; Udall and Overpeck, 2017) versus a decrease in hydrological drought frequency (Mo and Lettenmaier, 2018), but in general there is strong spatial variability** (Roshiri and Pal, 2016). Streamflow observation reference networks of near-natural catchments have also been used to isolate the effect of climate trends on hydrological drought trends in a few regions, but these show limited trends in Northern Europe and Western and Central Europe (Stahl et al., 2010; Bard et al., 2015; Harrigan et al., 2018), North America (Dudley et al., 2020) and most of Australia, with the exception of Eastern and Southern Australia (X.S. Zhang et al., 2016).

p. 1575

Few AR6 regions show observed increases in meteorological drought (Section 11.9), mostly in Africa and South America (NES: *high confidence*; WAF, CAF, ESAF, SAM, SWS, SSA, SAS: *medium confidence*); a few others show a decrease (WSB, ESB, NAU, CAU, NEU, CNA: *medium confidence*). There are stronger signals indicating observed increases in agricultural and ecological drought (Section 11.9), which highlights the role of increased [evapotranspiration], driven by increased [Atmospheric Evaporative Demand], for these trends (Sections 11.6.2.3, 11.6.2.5). Past increases in agricultural and ecological droughts are found on all continents and several regions (WAF, CAF, WSAF, ESAF, WCA, ECA, EAS, SAU, MED, WCE, NES: *medium confidence*), while decreases are found only in one AR6 region (NAU: *medium confidence*). The more limited availability of datasets makes it more difficult to assess historical trends in hydrological drought at regional scale (Section 11.9). Increasing (MED: *high confidence*; WAF, EAS, SAU: *medium confidence*) and decreasing (NEU, SES: *medium confidence*) trends in hydrological droughts have only been observed in a few regions.

AR6 on Attribution (p. 1577)

There are only two AR6 regions in which there is at least *medium confidence* that human-induced climate change has contributed to changes in meteorological droughts (Section 11.9). In South-western South America (SSW), there is *medium confidence* that human-induced

climate change has contributed to an increase in meteorological droughts (Boisier et al., 2016; Garreaud et al., 2020), while in Northern Europe (NEU), there is *medium confidence* that it has contributed to a decrease in meteorological droughts (Gudmundsson and Seneviratne, 2016) (Section 11.9). **In other AR6 regions, there is inconclusive evidence in the attribution of long-term trends, but a human contribution to single meteorological events or subregional trends has been identified in some instances...** In North America, the human influence on precipitation deficits is complex (Wehner et al., 2017), with low confidence in the attribution of long-term changes in meteorological drought in AR6 regions.

8.3. Extreme weather trends at global and continental scale

8.3.1 Tropical Cyclones (TCs)

Hurricane strength records for the North Atlantic and the Western Pacific go back to 1950 and the record does not show an increase in either total or major TCs. Figure 8.31 was published by Roger Pielke Jr. as an update to the Best Track data series originally presented in Weinkle et al. (2012).

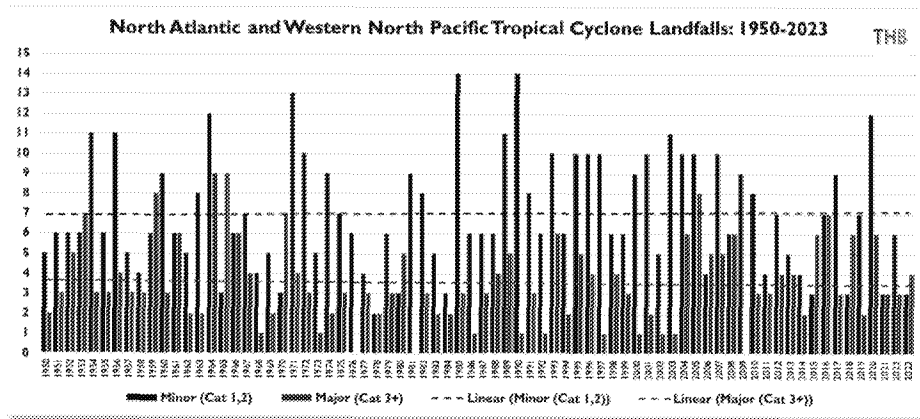


Figure 8.31. Tropical Cyclone Landfalls. Source: [[HYPERLINK "https://rogerpielkejr.substack.com/p/global-tropical-cyclones"](https://rogerpielkejr.substack.com/p/global-tropical-cyclones)], Weinkle et al. (2012)

Similarly, Figure 8.32 (Maue 2025, [[HYPERLINK "https://climatlas.com/tropical/"](https://climatlas.com/tropical/)]) shows that both all hurricanes and major hurricanes have not become more common since 1980, the

Commented [A7]: Cite the Climate Atlas of Dr. Ryo Maue

period of rapidly growing human influences. In fact, both numbers have trended down slightly since the 1990s:

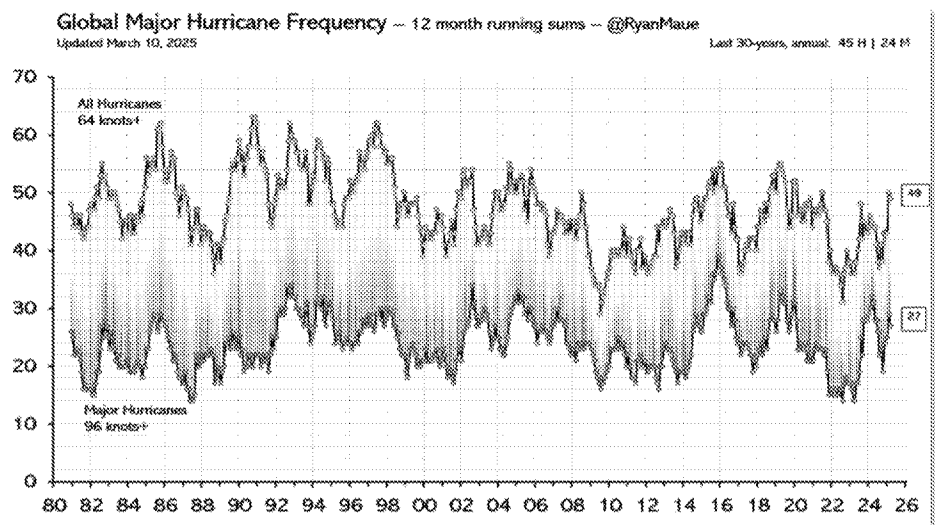


Figure 8.32: Global hurricane frequency. Source: Maue (2025)

A metric that combines the number, duration, and strength of TCs is the Accumulated Cyclone Energy (ACE) Index maintained at Colorado State University, shown in Figure 8.33. It clearly shows no long-term increase, in fact declining slightly since 1990.

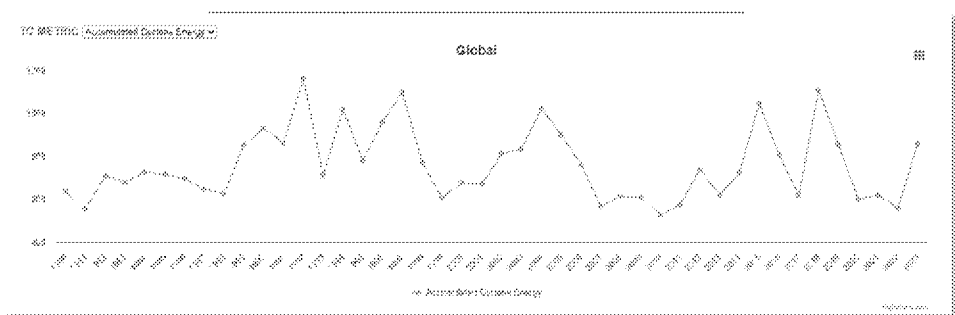


Figure 8.33: Global Accumulated Cyclone Energy. Source: Klotzbach (2025)

[HYPERLINK "<https://tropical.atmos.colostate.edu/Realtime/index.php?arch&loc=global>"]

Note that Tu et al. (2024) report that the Power Dissipation Index (FDI), another different measure that combines hurricane number, duration, and strength, has either remained unchanged or has declined in all global oceanic basins since the mid-1990s.

Today's global climate simulations are too coarse to project changes in TCs directly. Rather, projections are derived from finer "downscaled" simulations or proxies involving sea surface temperatures, winds, and aerosols. By those methods, a warming climate is expected to show declining hurricane formation rates. (Chand et al. 2022). Climate models also project fewer Tropical Cyclones under future global warming, and even though models project they will increase in strength, the annual averages of rainfall maxima decline (Stansfield et al. 2020).

8.32 Wildfires

As shown in Figures 8.34 and 8.35 global wildfire activity as measured by European Space Agency peaked over a decade ago and shows a downward trend since.

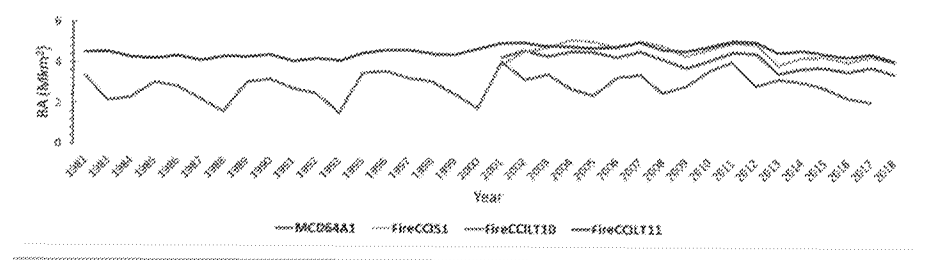


Figure 8.34: Global wildfire 1982-2018. Source: Copied from Oton et al. (2021). Note: the different coloured lines represent different data products based on satellites and algorithms used.

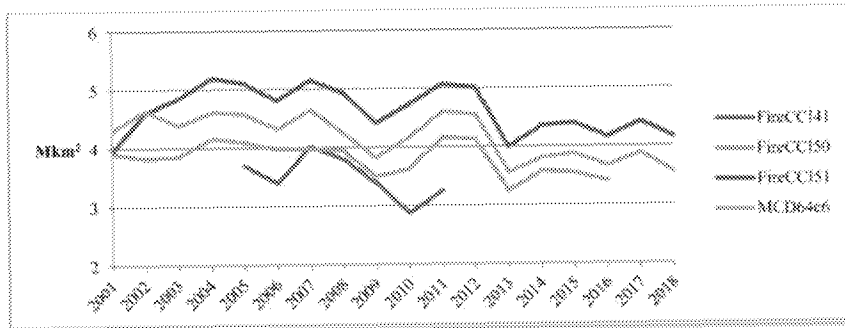


Figure 8.35: Global wildfire 2001-2018. Source: Copied from Lizundia-Loiola et al. (2021).
 Note: the different coloured lines represent different data products based on satellites and algorithms used

Commented [A8]: I thought the trends were due to declining fires in the Amazon, masking any climate-related trend?

US data from the National Interagency Fire Centre (NIFC) from 1926 to 2023 are shown in Figure 8.36.

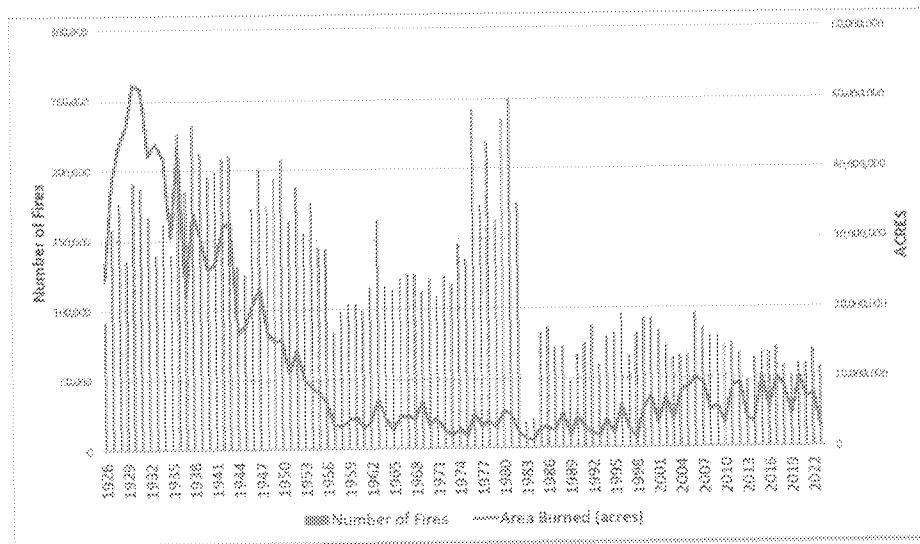


Figure 8.36: US wildfires 1926 to 2023. Source: National InterAgency Fire Centre data
 Pre-2017 (archived)

[HYPERLINK

"file:///C:/Users/Porter%20Hill/Dropbox/Brucehaven/Projects/DoE/Ross%20drafts/Pre-2017)/%20https://web.archive.org/web/20200212033452/https://www.nifc.gov/fireinfo/fireinfo_stats_totalFires.html"]. 2018-2023: [HYPERLINK "https://www.nifc.gov/fire-information/statistics/wildfires"]

Note the NIFC has removed the pre-1960 data from its current website. They claim it is because measurement methods changed after 1960. This explanation seems inadequate since agencies blend temperature and extreme weather data series in other contexts when measurement systems changed. In this case if anything the measurement of wildfires has improved since the early 20th century so any bias will be towards understating early wildfire counts. Nonetheless just focusing on the post-1985 interval the number of fires is not increasing. The area burned did increase but only until about 2007.

It is difficult to establish a natural baseline for wildfire activity because of active fire suppression activity since 1900. Paleoclimatic evidence indicates, however, that past wildfire activity was much higher than at present. Marlon et al. (2012) used sedimentary charcoal layers to reconstruct fire history of western US for the past 1400 years. They also fit a model to predict expected fire activity as a function of climatic conditions. The results are summarized in Figure 8.37 below (from Figure 2 in their paper).

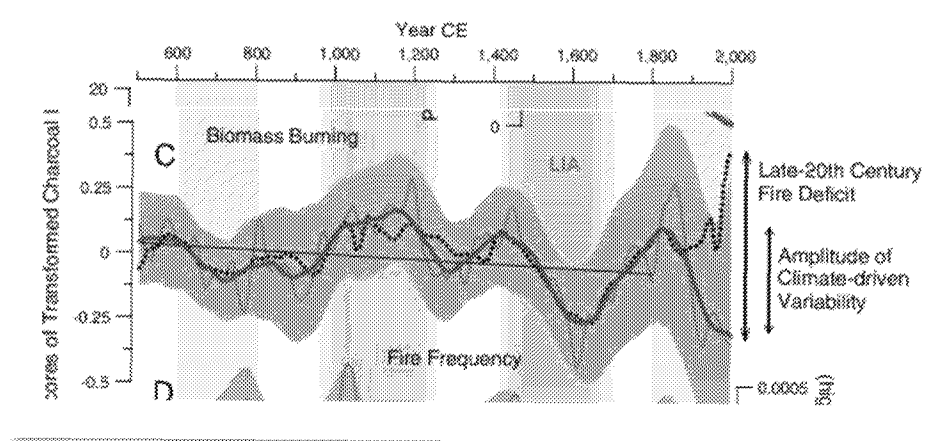


Figure 8.37: Fire frequency and fire deficit in the US. Source: Copied from Marlon et al. (2012)

In their figure the red line shows the smoothed charcoal record and the black dotted line shows the predicted charcoal record based on the statistical model. The gap at the end implies there has been a growing wildfire deficit over the 20th century. In other words, however much fire was observed in the 20th century it was less than what would have been observed in previous

centuries based on the climatic conditions. Parks et al (2025) likewise find that despite the recent increase in wildfire burn area in North America, a significant wildfire deficit remains relative to historical wildfire regimes.

8.3.3 Precipitation

Figure 8.38 shows that US long term data from NOAA shows an insignificantly increasing tendency toward extreme wetness (+0.0001% per year)

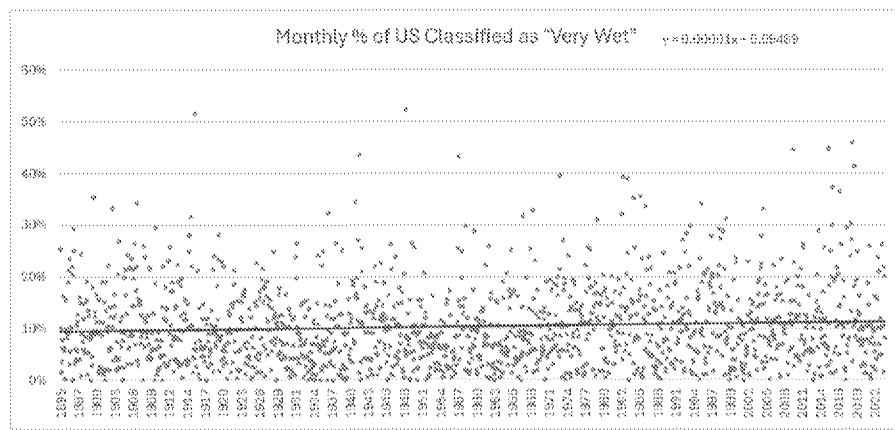


Figure 8.38: Long term US wetness (%). Source: NOAA [[HYPERLINK "https://www.ncsl.noaa.gov/access/monitoring/uspa/wet-dry/0"](https://www.ncsl.noaa.gov/access/monitoring/uspa/wet-dry/0)]

Precipitation will be discussed further in the review of CONUS data below.

8.3.4 Drought

As shown in Figure 8.39 US long term data (NOAA) shows an insignificantly declining tendency toward extreme dryness (-0.001% per year)

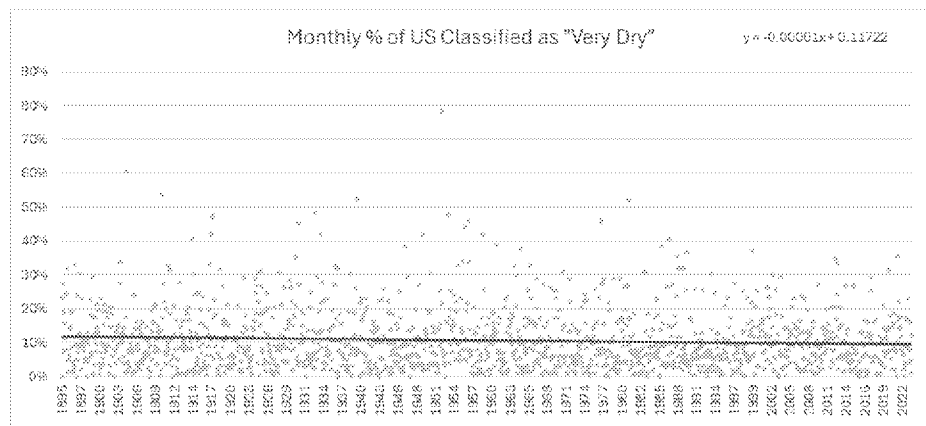


Figure 8.39: US dryness (%) 1895—2023. Source: NOAA [[HYPERLINK](https://www.ncei.noaa.gov/access/monitoring/uspa/wet-dry/0) "https://www.ncei.noaa.gov/access/monitoring/uspa/wet-dry/0"]

Kogan et al. (2020) examines a 38-year high-resolution satellite-based drought measure and concludes that global drought has not intensified and is not connected to climate change: “it is possible to state firmly that global and main grain countries’ drought area and intensity trends have not been following global climate warming since 1980’s.”

8.4. Temperature and precipitation extremes in the Contiguous US (CONUS)

8.4.1 CONUS daily temperatures are becoming less extreme

Daily maximum temperatures in the warm season (TMax, May-Sep) and daily minimum temperatures in the cold season (TMIn, Dec-Mar) are available beginning in Dec 1898 (126 years). The dataset consists of 1,211 CONUS stations designated as United States Historical Climate Network or USHCN stations (Quinlan et al. 1987, Karl et al. 1990). These stations were selected by NOAA as having the fewest problematic issues with gaps, station moves and instrument changes. Where gaps still exist, nearby stations (bias-corrected) were merged so that the median volume of data available for a station is 98%. Although there are certainly errors in the dataset, with over 1,000 stations we can have relatively high confidence in any underlying signal that might be discovered.

Commented [A9]: Again, I think we need a map of where the stations are; something like this one:
[[HYPERLINK](https://www.researchgate.net/publication/258660497_Uncertainties_Trends_and_Hottest_and_Coldest_Years_of_US_Surface_Air_Temperature_since_1895_An_Update_Based_on_the_USHCN_V2_TOB_Data/figures?lo=1) "https://www.researchgate.net/publication/258660497_Uncertainties_Trends_and_Hottest_and_Coldest_Years_of_US_Surface_Air_Temperature_since_1895_An_Update_Based_on_the_USHCN_V2_TOB_Data/figures?lo=1"]
More importantly, it needs to show how you’ve cut them up into regions

We begin with the question of whether the occurrence of daily record high or low temperatures changed has changed since Dec 1898. Each warm-season has 153 days (1 May to 30 Sep) and each cold-season has 122 days (1 Dec to 31 Mar). For each station and day, we calculated the year in which the record highest (lowest) temperature occurred. With 126 years of observations, if there were no temperature trends over time,—the expected number of records for TMax would be 1.21 (=153/126) per station per year and for TMin 0.96 (=122/126) per station per year. Figure 8.4.1 indicates the observed distribution in time of the occurrence of these extreme events.

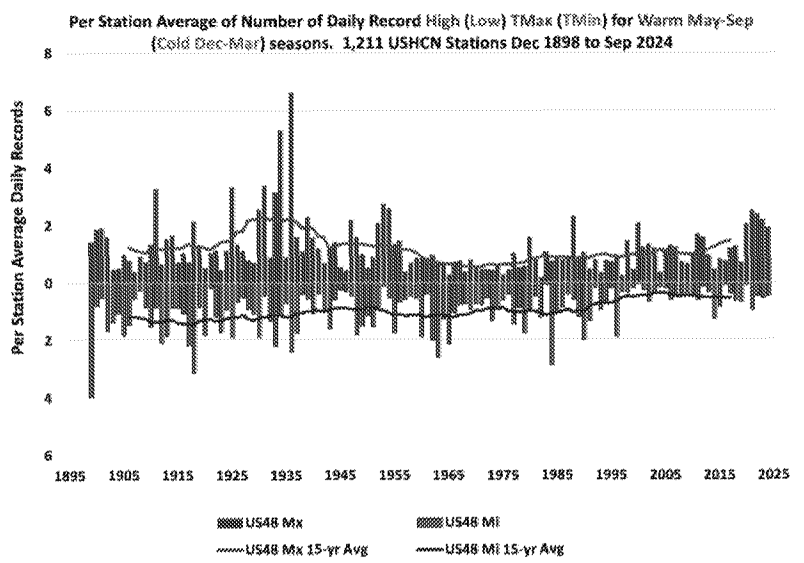


Figure 8.4.1 Number of daily record High (red) and Low (blue) for warm and cold seasons in the CONUS. The lines represent the 15-year running, centered average. Source: 1,211 USHCN stations supplemented as needed to achieve a minimum of 92% of observations in the 126-year period since Dec 1898.

The results indicate a common feature in many metrics of warm-season extremes in the CONUS - the exceptional heat of the 1920s and especially the 1930s, peaking in 1936. On a per-station average, 60% of the TMax records and 59% of the TMin records occurred in the first half of the period (1899-1961).

On the cold side, the Valentine's Day Arctic outbreak in Feb 1899 stands as the most extensive cold extreme experienced by the CONUS, with 1917 2nd. The frequency of cold records has declined, especially over the last quarter of the period in which only 13% of the extreme cold events were measured. In contrast, 25% of the extreme TMax records were achieved in the last quarter in accordance with statistical expectations. These general features have been noted in past assessments (IPCC AR5, IPCC AR6, NCA4, NCA5). Combining the two records the overall

reduction in numbers of both cdd and hot extremes over the past century indicates a climate less prone to extremes.

This pattern is also shown in Figure 8.4.2. For each station and for each year the hottest warm season and coldest cold-season temperatures were calculated and converted to anomalies relative to the station's long term warm and cold season (respectively) averages. Then the differences between these were computed by station and geographically-averaged over all stations, thus yielding an annual measure of the expected range of local extreme temperatures for each year. Figure 8.11 shows the 15-year trailing average of this measure which has clearly declined over the past century.

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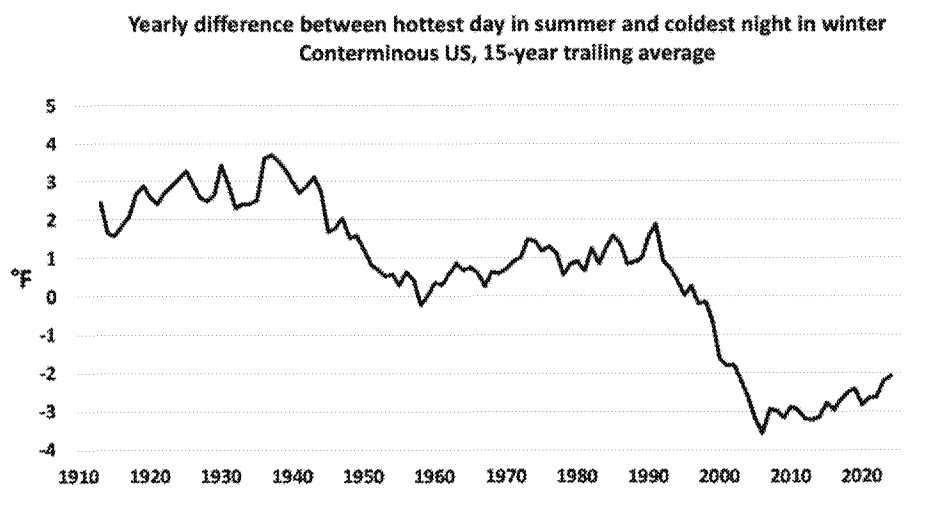


Figure 8.4.2. 15-year trailing average of the difference each year of each station's hottest warm-season TMax and coldest cold-season TMin relative to the long-term average.

The average difference for each station between the hottest summer TMax and coldest winter TMin has declined about 5°F in the past 126 years. The decline is due mostly to warming winter TMin, but a decline in the magnitude of summer TMax is also a factor. The rise in TMin has been strongly related to the growing presence of manufactured surfaces around the weather stations over the last 100+ years (Spencer et al. 2025).

Summarizing Figures 8.4.1 and 8.4.2, while temperature extremes are regularly experienced in the US and attract a great deal of media attention, long term records show the US climate has become less extreme over time (milder) when measured in terms of the range between warm season maxima and cold season minima.

8.4.2 Exceedances of a heat threshold

Under the heading of “The Risk of Temperature Extremes is Changing”, the most recent US National Climate Assessment report (NCA5) notes the increase in a threshold metric of number of days at or above 95°F, stating,

“The western US has been particularly affected by extreme heat since the 1980s ..., experiencing a larger increase in days over 95°F, as would be expected given the greater warming in that region relative to the eastern US. Several major heatwaves have affected the US since 2018, including a record-shattering event in the Pacific Northwest in 2021.”

Are the occurrences of 95°F days changing? In a climate as varied as that of CONUS, threshold statistics can be misleading. A region with many stations that have near 95°F TMax average temperatures in the summer might see large swings in the metric when only small changes in average temperature occur. Elsewhere with stations that either rarely or virtually always achieve 95°F TMax temperatures, a small change will not impact the results much at all. In the past 126 years, the average CONUS station experienced 129 days exceeding 95°F per 6-yr period, but the regional values range from 278 in the Southern Plains to 9 in the Northeast. Thus, one needs to view such threshold analyses with caution.

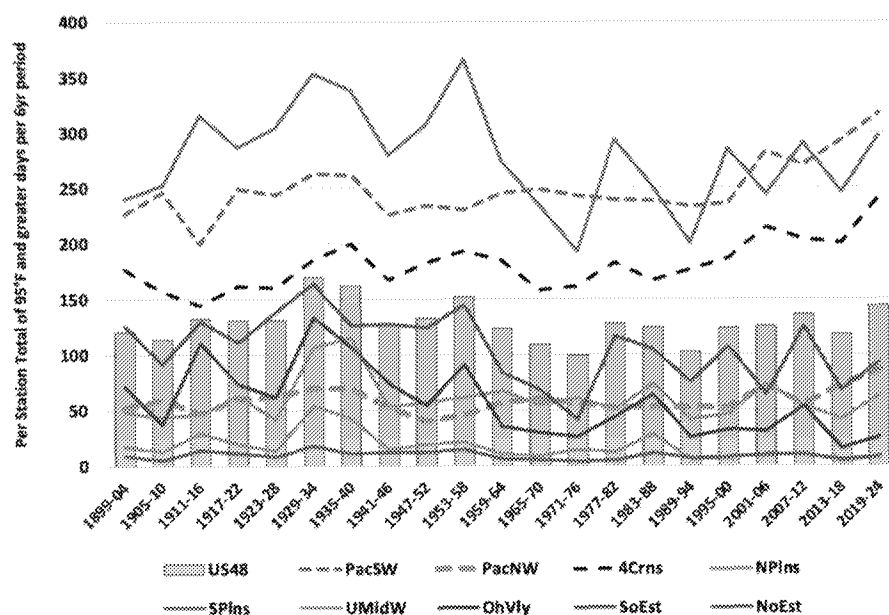


Figure 8.4.3. Total number of days $\geq 95^{\circ}\text{F}$ in 6-yr periods, US 48 (bars) and regions (lines).

In Fig. 8.4.3 we see that only three of the nine regions, all in the West, have experienced upward trends in the number of 95°F or hotter days (dashed lines). The CONUS as a whole has not and the other six regions have experienced declines.

The Pacific NW heatwave of 2021 is referenced as of the NCA5 claim, an event we examine more closely in Section 6.4. The evidence indicates it was a “black swan” event; *i.e.*, a single, unprecedented event in the record, not part of a pattern of increasing extreme heat. For example, the 5-day average tropospheric grid-point temperature anomaly over the Pacific NW during that event was +10.8 C, the most extreme NH grid point summer anomaly in the 46 years from over 4 million grids. In contrast, the global anomaly during that time was virtually zero (+0.03 C, Mass et al. 2024).

The heading “The Risk of Temperature Extremes is Changing” suggests positive trends are now being observed in threshold temperatures on a widespread basis, but that is not evidenced in the combined CONUS results of the figures above.

8.4.3 Heatwaves

Heatwaves (consecutive days that exceed an extreme threshold) have a greater societal impact than a single daily record. We measure “Heatwave Days” here as the count of all days in May-Sep each year that exceed the 90th percentile and that lie within a run of at least six consecutive days. This is equivalent to the method used in NCA5 except that the reference period here is the entire record 1899-2024 while NCA5 truncated the reference period to 1961-1990, a cool time. That truncation boosts positive results (days exceeding the 90th percentile) in periods warmer than the reference period, especially starting in 1960 and moving to the present (see *Urban Influences* below).

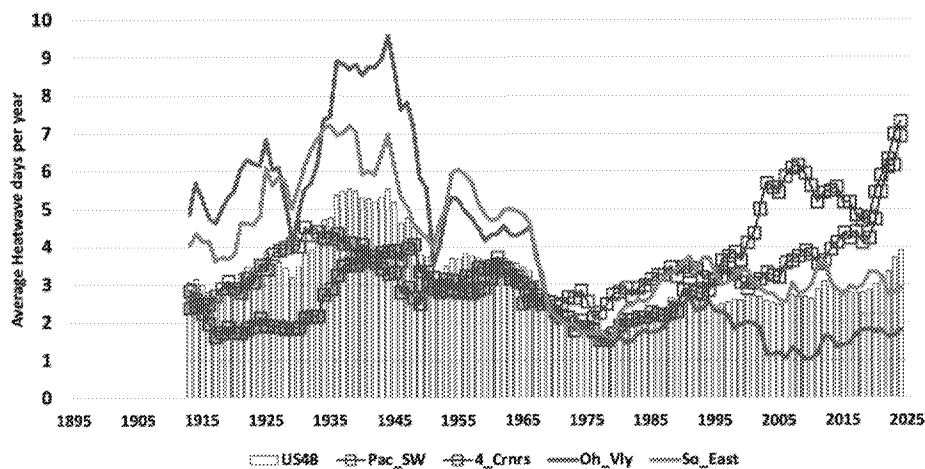


Figure 8.4.4 15-year trailing average of number of heatwave days per year per station in the CONUS (bars) and four regions: Pac_SW (purple squares, CA, NV), 4_Crnrs (red squares, AZ,NM,UT,CO), Oh_Vly (blue, MO, IL, KY, TN, IN, OH, WV) and So_East (green, MS, AL, GA, FL, SC, NC, VA).

Figure 8.4.4 indicates again the excessive heat of the first half of the 20th century, primarily in the eastern two-thirds of the nation, as seen in the regional values for the Ohio Valley and the Southeast as examples. The West has seen a recent increase of heatwave days and the two regions with the highest number are shown, the Pacific Southwest and the Four-Corners (NCA5). This indicates that the background warm season circulation favored heatwaves in the eastern portions of the country in the first half of the 20th century, but in the 21st century the patterns have favored heatwaves in the West. For CONUS as a whole, heatwaves are no more common today than they were a century ago.

Of interest here is the regional variation of this metric. The four northern regions (Pacific NW, Northern Plains, Upper Midwest, and Northeast) on average experience 15 to 27 heatwave days per 15-year period. In contrast, the five southern regions (Pacific Southwest, 4-Corners, Southern Plains, Ohio Valley and Southeast) see 37 to 54 such days, essentially twice as many. This suggests the summer circulation pattern is more prone to stationary events in the southern regions while transient systems in the northern regions are more common and thus cut short these potentially longer events.

Urban influences

The NCA5 directs readers to the website [[HYPERLINK "https://www.globalchange.gov/indicators/heat-waves"](https://www.globalchange.gov/indicators/heat-waves)] (USGCRP 2023) to view the number of urban heatwaves by decade from the 1960s. The figure shows a monotonic increase in each decade from 2 occurrences per year in the 1960s to 6 in the 2020s. The definition of a heatwave is an unusual but practical measure of human discomfort - a period of at least 2 consecutive days when the minimum apparent temperature (combination of temperature and humidity) exceeds the 85th percentile. Note too, the dataset is limited to the 50 largest U.S. cities.

These increasing values since 1960 presented in USGCRP (2023) are entirely reasonable, but are unrelated to GHG emissions for at least two reasons. Urbanization in these cities is a major factor in the rise of TMin relative to co-located TMax and relative to TMin at rural stations. Also, the 1960s was the coldest decade and 1970s the second coldest decade since the 1910's, so this starting date preconditions the time series to show increases. This does not dismiss the real rise in nighttime temperatures in major U. S. cities and the societal impacts associated with these changes. However, we note for a variety of reasons, that summer TMax (especially in rural areas) serves as better response variable for detecting potential changes in heatwaves influenced by changes in the background climate due, for example, to increasing GHGs (Christy et al. 2009). For the CONUS as a whole, the evidence in this section suggests GHG emissions have had little-to-no effect on heatwaves.

8.4.4 Extremes in daily precipitation.

Because precipitation involves a discrete phase change (water vapor to liquid), it is stochastic and episodic in character and requires careful statistical treatment to understand variability over long time periods (see 8.1 Introduction). The US National Climate Assessments (NCA4, NCA5) have highlighted an increase in the occurrence of the heaviest precipitation events (defined in different ways) primarily in the eastern half of the CONUS, especially the Northeast, when starting in either 1901 or 1958. Interestingly, the regional variations indicate that the largest increases in extreme events are in the Northeast and the smallest in the West, a trend counter to the changes in temperature extremes.

Commented [A11]: Stochasticity and LTP are really different things, but we somehow conflate them in this sentence. Or am I missing something?

Commented [A12R11]: By removing the 'therefore' I think we are now not conflating them.

McKittrick and Christy (2019) examined long-term and consistent station observations of daily precipitation to test some of these NCA claims for the Southeast and West Coast. When the time series were extended back in time (as far as 1872 in some cases) or when starting later (1978), there

were no significant trends for either region. For this report we updated these findings with similarly constructed observations from 29 stations on the Pacific Coast (1893ff from San Diego CA to Blaine WA), 24 stations in the humid Southeast (1872ff from Austin TX to Washington DC), and 21 stations in the Northeast (1888ff from Buffalo NY to Gardiner ME). The results were as follows.

Pacific region:

- Average precipitation trend is significant (downwards) in Astoria, insignificant elsewhere.
- The trend in rainfall variance is positive and significant in Big Sur, insignificant elsewhere.
- The trend in daily maximum precipitation is positive and significant in Aberdeen and Big Sur and negative and significant in Newport (insignificant elsewhere).
- Averaged over all stations in the region none of these three trend parameters is statistically significant.

Southeast region:

- The trend in average precipitation is positive and significant in Mobile and Quitman, insignificant elsewhere.
- The trend in rainfall variance is positive and significant in Mobile, insignificant elsewhere.
- The trend in daily maximum precipitation is positive and significant in Vicksburg and Norfolk, insignificant elsewhere.
- Averaged over all stations in the region none of these three trend parameters is statistically significant

Northeast region:

- The trend in average precipitation is positive and significant in 9 of 21 locations and in the region averaged overall.
- The trend in rainfall variance is positive and significant in Portland, Albany and Buffalo, insignificant elsewhere.
- The trend in daily maximum precipitation is positive and significant in Portland and Gardiner, insignificant elsewhere.
- Averaged over all stations in the region the trend parameters for variance and maximum precipitation are not statistically significant.

Pacific Coast heavy rainfall events

The Pacific Coast receives considerable precipitation from Atmospheric River (AR) events which often last more than a day or two (e.g., Gershunov et al. 2017, Pan et al. 2024). The worst-known such event in recent history was the ArkStorm that occurred between December 1861 and January 1862, which dumped nearly 10 feet of rain in parts of California and submerged the entire Central Valley for weeks under as much as 15 feet of water (Brewer 1930, Null and Hulbert 2007). Paleoclimate research has found six megastorms more severe than 1861–1862 in California during the last 1800 years, occurring at intervals of 300 years or so (Porter et al. 2011).

SIDEBAR: Perils of short data records

San Francisco provides a good case study of the limitation of using short historical samples to characterize natural variability of extreme events. Suppose we use a 130-year sample of daily San Francisco precipitation from 1895 to 2024 and we look for 3-day, 5-day, 14-day and 30-day rainfall records. The results are as shown in Table 8.2.

Event	Record (inches)	Year
3-day	6.94	2023
5-day	8.55	2023
14-day	12.62	2023
30-day	18.93	1998

Table 8.2: Extreme rainfall records, San Francisco, 1895-2024.

The records all cluster in the more recent data. 2023 appears to be an exceptional year and since it is near the end of the sample it might suggest that the climate has shifted into a more hazardous state, perhaps as a result of human influences.

But the picture is very different if we use a sample that begins 45 years earlier, in 1850. Table 8.3 shows that the record-setting events then all happened in the 1860s. Furthermore 2023 is now not even in 2nd place but falls to 3rd or 4th. Also, comparing the records of the two charts the extreme precipitation events in 1862 and 1867 involved considerably more rainfall than the 1998 and 2023 events, with 14- and 30-day totals about 50 percent higher.

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Event	Record (inches)	Year	Rank of 130-yr extreme
3-day	8.85	1867	3
5-day	9.80	1867	3
14-day	19.05	1862	4
30-day	28.25	1862	2

Table 8.3: Extreme rainfall records, San Francisco, 1850-2024.

The range of natural variability is made even more remarkable when paleoclimate evidence is examined. Porter et al. (2011) discovered that in the past 1,800 years at least six megastorms were more intense than the devastating 1861-62 ArkStorm that struck the region. Evidently such extreme events have impacted the region about every 300 years, though not since 1895.

This example illustrates the limitations of using relatively short climate periods (~130 years) to assess the character and range of natural variability in general and of extreme events in particular. Accurate representation of the full range of natural variability is necessary for any attribution analyses (see 6.4). Infrastructure planners, emergency management institutions and attribution scientists would understand the significant mischaracterization of the magnitude of a future extreme if based only on the last 130 years. In this case, a single time-sample of 130 years provides an underestimation of the extreme value by up to 50% determined when adding only 45 more years of observations. Compared to millennial-scale paleoclimate evidence, an even greater underestimation would occur. An important lesson is that the climate can deliver great surprises on its own, even without human influences.

We examine occurrences of 5-day deluges as follows. In a 130-year span there are 26 5-year intervals. At each location we computed the 5-day precipitation totals throughout the year and selected the 26 highest values. A single year may have more than one of the 26 heaviest. Each of those can be thought of as 1-in-5yr events. If there are no trends in precipitation then the total number of these events across all stations should be evenly spread out over the years. In Fig. 8.4.5 we show the distribution

in time of these events. The deluges associated with the massive 1997-98 El Niño event are readily apparent. While erratic, as is typical of these types of precipitation metrics, there is no indication of a tendency to become more frequent over time.

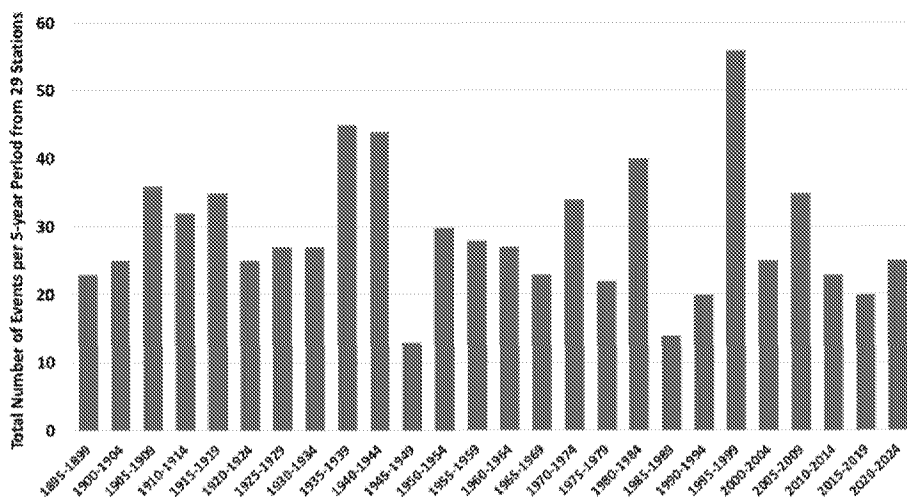


Figure 8.4.5. The time distribution by 5-year periods of the 26 heaviest occurrences for each station (i.e., nominal 1-in-5 year event).

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Southeast heavy rainfall events

The temporal pattern of 5-day totals of the 1-in-5yr heavy events in the humid Southeast (Figure 8.4.6) is generally unremarkable, though a cluster of higher values appears in 1995 to 2019. The increase in those years is due largely to the 4 northeastern-most stations of Wilmington NC, Weldon NC, Washington DC, and Norfolk VA. This confirms the pattern indicated in NCA4 and NCA5 of a tendency for an increasing frequency of heavy events, due to a temporal clustering of tropical storms from eastern NC to Maine discussed below. Otherwise, the remaining 20 stations show an unremarkable temporal distribution of heavy events.

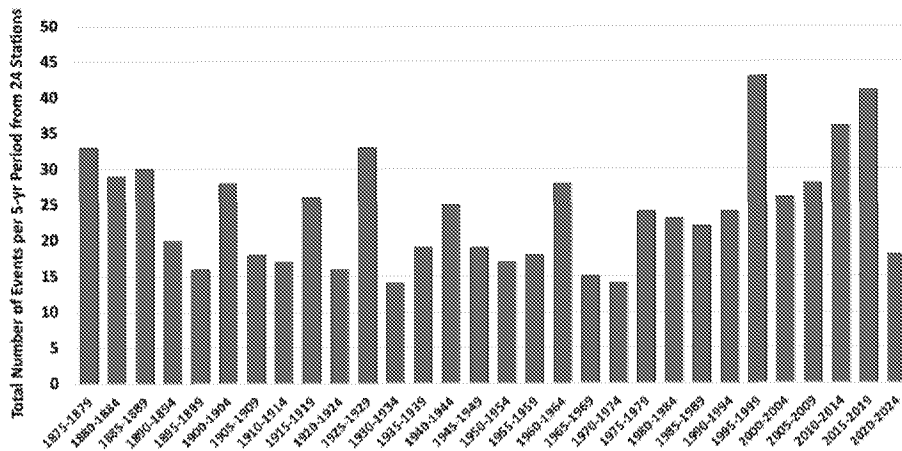


Figure 8.4.6. As above but for the 30 heaviest 1-in-5yr events for 24 stations in the humid Southeast from Austin TX to Washington DC in 5-year bins for 1875-2024.

Northwest heavy rainfall events

Fig. 8.4.7 shows the 27 (1-in-5yr) heaviest 3-day events for the last 135 years in 21 stations in the Northeast (including Montreal Canada). We use 3-day totals here as this produced the largest variations in time. In this region, 72% of the events occur during June to October and are dominated by tropical incursions of hurricanes, tropical storms or tropical storms that transition to extratropical systems. According to NCA4 and NCA5 this region experienced the largest increases in extreme events, so it shall be examined more closely.

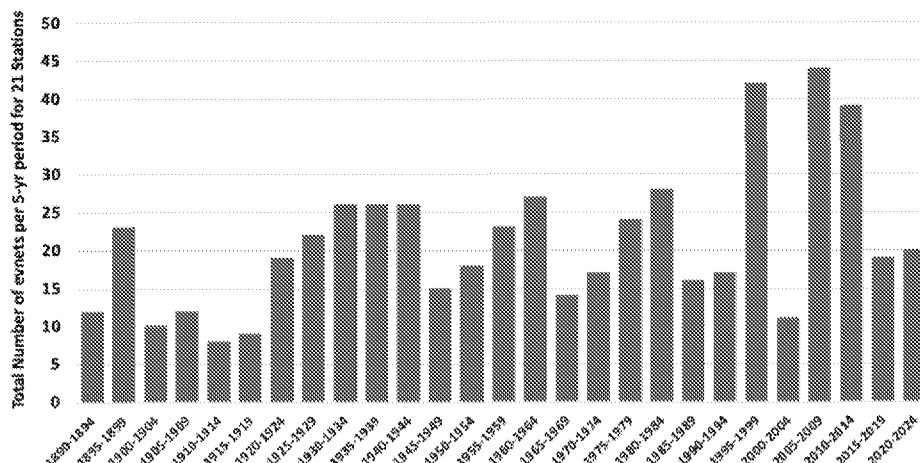


Figure 8.4.7. Time distribution of the heaviest 27 (1-in-5yr) heaviest 3-day precipitation events for 21 stations from NY to ME, including Montreal.

Howarth et al. (2019) report differences in the Northeast between two 18-year periods: 1979-96 and 1997-2014 (a similar region as in Fig. 8.16 that includes PA and NJ) of various precipitation extremes. One metric which indicated a dramatic increase (317%) was found for 24-hr events > 6 inches. This high increase is due to the very small numbers of such events of which there were only 6 in the first period and 25 in the second as reported for 58 stations. This high percentage increase is due to the very small numbers of the events; only 6 in the first period and 25 in the second. Most of the stations, did not record such an event suggesting these erratic, episodic events over brief, 18-yr periods, need scrutiny by additional statistical methods.

Using the information in Fig. 8.4.7 over the same years as Howarth et al. we find a 51% increase in the frequency of heavy events between the two periods. One can see in Fig. 8.16 that it was unfortunate that Howarth et al. ended in 2014 prior to a return to the long-term average of such events.

A feature of Howarth et al. is the use of single day totals which is questionable because extreme events are often spread across the time-of-observation boundary. Thus stations measuring at 0700 LT versus those at Midnight will have differing results for a particular event which would then have major impacts on counting these events. We use the 3-day totals in Fig. 8.4.7 to be sure to capture the extent of these extreme downpours. In any case, we can confirm that the period 1997 to 2014 experienced a cluster of heavier events as Howarth et al. have documented.

Howarth's most remarkable claim (317% increase in 6" days) is potentially misleading because it is a threshold statistic (see Section 8.4.2 above) and a ratio of small numbers over a short period. The result is not representative of *relative* extreme events for the whole region since the majority of stations never experienced a 6" total. Fig. 8.16 above determines the same number of events for each station (27 heaviest events) whose heaviest values ranged from 4.4" to 12.5" and their 27th heaviest values ranged from 3.3" to 5.0". This analysis thus allows each station to be equally represented. In

other words, if there is a region-wide increase in heavy events, it should be seen in the sum of all stations. Note too that the period of record here is 135 years vs. 36 years of Howarth et al. Except for three 5-year periods between 1995 and 2014 there is nothing statistically remarkable about the results in Fig. 8.4.7.

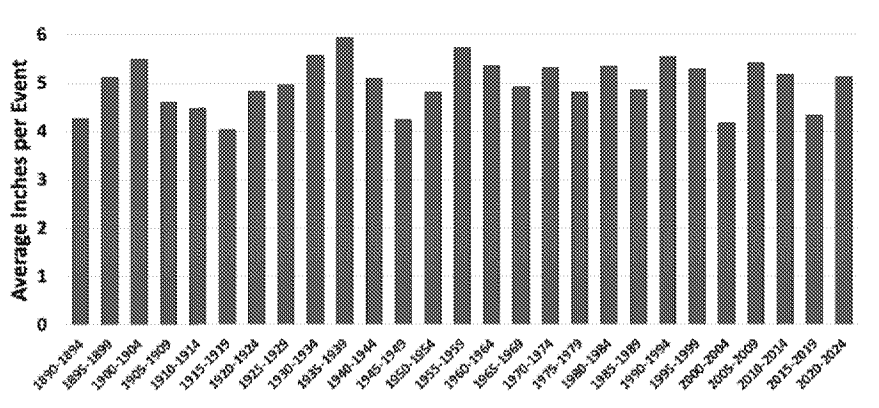


Figure 8.4.8. Average amount of precipitation falling in the 1-in-5yr events for the NE stations.

An interesting aspect of Northeast precipitation is that there has been no change in the amount of precipitation per heaviest event, as shown in Fig. 8.4.8. The trend is only $+0.02''/\text{decade}$. The highest amount, 1935-39, includes the Great New England Hurricane of 1938, one of the rare major (Category 3 or higher) hurricanes to strike the region. The results in Figs. 8.4.6 and 8.4.7 suggest that though there was an uptick in the number of events during the period 1995 to 2014; the events, individually, are not becoming more intense.

Jong et al. (2024) document the increase of tropical influences on precipitation events in the Northeast since 1959 and concluded, "The autumn extreme precipitation trend over the Northeast US is primarily attributed to tropical cyclone-related events since the 1990s." The question then becomes, was the temporal clustering of tropical systems in 1997-2014 which affected the Northeast a response to increasing GHGs? Jong et al. examined CMIP-6 model output which suggests that there will be fewer such systems in the 21st century but that the intensity of the rainfall events might increase. This conjecture is not seen in Fig. 8.17 where the amount-per-event has remained steady over the 135-year period.

For substantial urban areas there is some evidence to indicate the heaviest rainfall events may be redistributed due to the impact urban infrastructure has on the local weather (e.g., Pielke Sr. et al. 2011, Zhang et al. 2018, Yang et al. 2024). Yang et al. state, "Cities that experience compact development tend to witness larger increases in extreme rainfall frequency over downtown than their rural surroundings, while the anomalies in extreme rainfall frequency diminish for cities with

dispersed development.” While this is an important insight to consider, the effect on the specific stations used in this analysis is unknown, or at least not detectable in Fig. 8.17.

In summary, the evidence from the historical record of extreme precipitation events in the CONUS is generally not consistent from region to region so that inferences regarding trends and their projections are wrought with significant uncertainty. In most regions and perhaps all, it is our opinion that the very nature of the erratic and episodic character of extreme precipitation events renders the discovery of statistically significant changes, including a relationship to CO2 concentrations, a result yet to be achieved (McKittrick and Christy 2019).

8.5 Summary

Based on the content provided in the document, here are the five most important takeaways:

1. Limited Detection of Anthropogenic Signals: The IPCC has asserted high confidence in detecting an anthropogenic signal in only 4 out of 34 weather impact categories, and medium confidence in 4 more. For the remaining 26 categories, no anthropogenic signal is claimed to be detected.
2. Slow Emergence of Trends: Even under the most extreme forcing scenario (RCP8.5), the IPCC expects very few anthropogenic trends to emerge within this century for most weather impacts.
3. Natural Variability Dominance: Natural variability continues to dominate patterns of extreme weather systems. Simple assertions of trend detection are often complicated by regional heterogeneity and trend reversals over time.
4. RCP8.5 Scenario Implausibility: The document notes that the RCP8.5 scenario is described as an implausible high-end storyline, not a “base case” or “business-as-usual” projection.
5. Conflicting Messages on Attribution: The document mentions that AR6 (IPCC Sixth Assessment Report) offers conflicting messages about the attribution of extreme weather to anthropogenic causes, highlighting the complexity and uncertainty in this area of climate science.

These takeaways emphasize the nuanced and complex nature of attributing extreme weather events to climate change, and the importance of considering natural variability and uncertainty in climate projections.]

Commented [A15]: Out of curiosity (and perhaps utility), I fed the entire document (absent this section) into Anthropic's Claude-3.5-sonnet LLM and asked it what are the five most important takeaways. This is what it produced. I'd judge it not a bad start that will need some human improvement, which I'll undertake on the next iteration.

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9. Changes in Sea level

Arguably the most important climate impact driver that is unambiguously associated with increasing temperatures is global sea level rise. Global warming increases sea level rise through thermal expansion of the volume of sea water and melting of glaciers and ice sheets. Another factor that influences sea level variations is land water storage. Regional sea level change is influenced by large-scale ocean circulation patterns, and geologic processes and deformation from the redistribution of ice and water. Local sea level rise is further influenced by vertical land motion from geologic processes, ground water withdrawal, and fossil fuel extraction.

The IPCC AR6 estimates that global mean sea level increased by 7.9 (5.9–9.8) inches between 1901 and 2018. The rate of sea level rise has accelerated in recent decades. At the ocean basin scale, sea levels have risen fastest in the Western Pacific and slowest in the Eastern Pacific over the period 1993–2018. The rate of global sea level rise is estimated to be 0.12 inches/year (for reference: 0.12 in is the height of two stacked pennies).

The observing systems for global sea level rise have advanced significantly in the satellite era, particularly with the advent of satellite altimeters since 1993. Local tide gauges have provided useful data for the past century, and even longer for a few locations. Following the end of the Little Ice Age in the mid-nineteenth century, tide gauges show that the global mean sea level began rising during the period 1820–1860.

9.1. U.S. coastal sea level rise

Observed and predicted rates of mean global sea level rise may have little relevance for specific locations. In Canada and Alaska (and also northern Washington), sea level is actually decreasing, owing to uplift from glacial rebound. Most of the Pacific coast has rates of sea level rise of 0 to 0.12 inches/year. The largest rates of sea level rise are on the Gulf coast (Louisiana and Texas) and in the mid-Atlantic states (Chesapeake Bay region).

Measurements of relative sea level rise from tide gauges conflate the rise in the volume of seawater with local vertical land motion. Hence in examining local sea level changes, it is important to also consider the local vertical land motion. Absolute local sea level rise is the sum of relative sea level rise and the local vertical land motion.

A wide range of processes can cause vertical land motion along the coasts, having amplitudes comparable to the sea level signals expected from land-ice melting or ocean thermal expansion. Vertical land motion on the coasts can locally exacerbate (subsidence/sinking) or mitigate (uplift) the risk of sea level rise. Local changes in sea level vary considerably from place to place and can deviate substantially from the rate of global mean sea level change. Human activities triggering subsidence are soil drainage (e.g. for urban development purposes) or subsurface mining of resources such as groundwater, oil or gas. The magnitude of relative sea level rise caused by human activities is often considerable. Local vertical land motion of relevance to local sea level change is best measured using a Global Positioning System (GPS) station located in the location as the tide gauge.

Table 8.1 shows absolute sea-level rise (ASLR) for selected locations, determined from the sum of uncorrected sea-level rise as estimated from tide gauge time series (RSLR) and the vertical land motion (VLM), measurements. The absolute sea level rise for each of these locations is significantly smaller than the measured relative sea level rise owing to local sinking of the land. More than half of the measured relative sea level rise is attributed to land sinking for these locations: San Francisco, Galveston, Grand Isle. For reference, the global average rate of absolute sea level rise is estimated to be 0.12 inches/year.

Table 8.1 Absolute sea level rise (inches/year) (RSLR plus VLM)

Location	RSLR	VLM	ASLR
San Francisco, CA	+0.08	-0.06	+0.02
Galveston, TX	+0.26	-0.19	+0.07
Grand Isle, LA	+0.36	-0.28	+0.08
St Petersburg, FL	+0.12	-0.02	+0.10
New York City, NY	+0.11	-0.05	+0.06

San Francisco Bay

Over the past 100 years, relative sea level in the San Francisco Bay area has risen by 7.8 inches, at an average rate of 0.08 inches/year (Figure 8.1). As shown in Table 6.1, San Francisco's vertical land motion is -0.06 inches/year (sinking), producing a recent rate of absolute sea level rise of +0.02 inches/year. Portions of Treasure Island, San Francisco International Airport, and Foster City are sinking as fast as 0.4 inches/year. Landfill zones are sinking due to soil compaction, at a rate as much as one-half inch per year, threatening coastal infrastructure including the San Francisco International Airport. The problems in the San Francisco Bay area have been caused primarily by sinking in landfill regions that were formerly wetlands, not by the slow creep of global sea level rise.

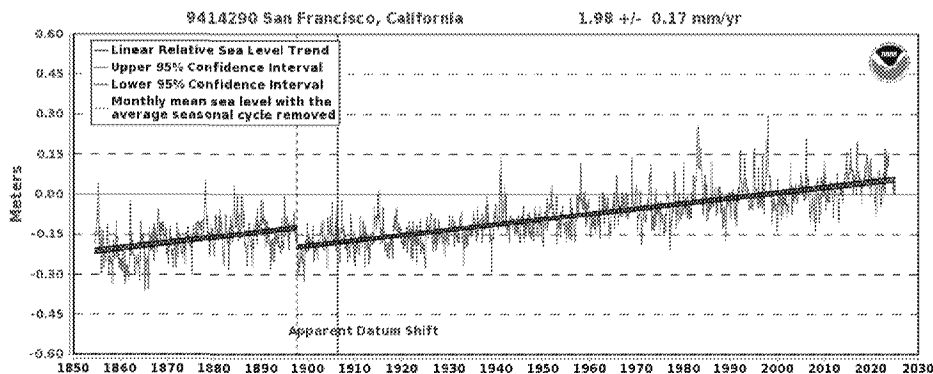


Figure 8.1. Tide gauge measurements at San Francisco, California, obtained from NOAA - https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=9414290 (downloaded 4/22/25).

Galveston - Houston

Long-term tide measurements at Galveston Pier 21 show sea level rise of 2.18 feet in the past century, or a rate of 0.26 inches/year (Figure 8.2). Vertical land motion (subsidence) at Galveston is estimated at -0.19 inches/year, yielding a value of absolute sea level rise of +0.07 inches/year (Table 8.1). The U.S. Geologic Survey found that most of the land-surface subsidence in the Houston-Galveston region has occurred as a direct result of groundwater withdrawals.⁶ This caused compaction of the aquifer sediments, mostly in the fine-grained silt and clay layers. By 1979, as much as 10 feet of subsidence had occurred in Houston.

Hurricanes are traditionally the major concern in the region. The 1900 hurricane that struck Galveston and killed between 6,000 and 12,000 people is still considered the United States' deadliest natural disaster.⁷ Hurricane Ike (2008) decimated large portions of the Bolivar Peninsula literally removing significant portions of the land mass.⁸ While only 17 people were killed in Texas, property damage exceeded \$50 billion.⁹ In 2017, Hurricane Harvey struck the region, bringing catastrophic rainfall-triggered flooding that inflicted over \$125 billion in damages.¹⁰

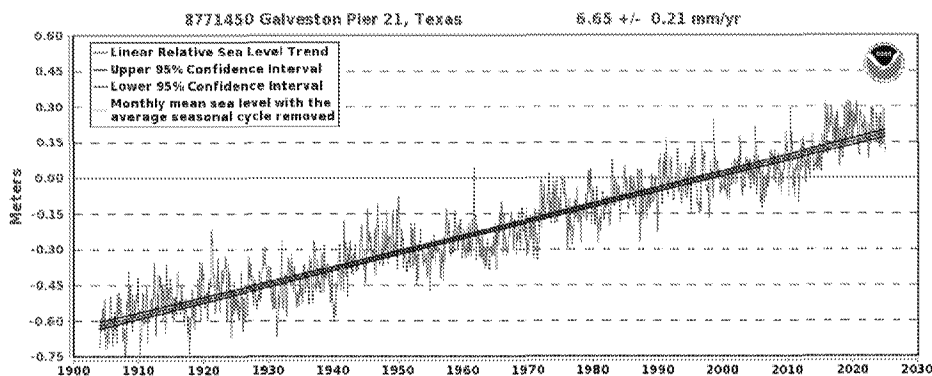


Figure 8.2. Tide gauge measurements Galveston Pier, TX, obtained from NOAA - https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=8771450 (downloaded 4/22/2025).

New Orleans and the Mississippi delta

⁶ Kasmarek, M.C., and Ramage, J.K., 2017, Water-level altitudes 2017 and water-level changes in the Chicot, Evangeline, and Jasper aquifers and compaction 1973–2016 in the Chicot and Evangeline aquifers, Houston-Galveston region, Texas: U.S. Geological Survey Scientific Investigations Report 2017–5080, 32 p., <https://doi.org/10.3133/sir20175080>.

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⁸ "Galveston County, Texas, Faces Sea Level Rise and Storms", Union of Concerned Scientists, (June 23, 2017) <https://www.ucs.org/resources/galveston-county-texas-faces-sea-level-rise-and-storms>.

⁹ White, Audrey, "Galveston Still Healing 5 Years After Hurricane Ike", The Texas Tribune, (April 26, 2013) <https://www.texastribune.org/2013/04/26/galveston-still-healing-5-years-after-hurricane-ike/>.

¹⁰ NOAA National Centers for Environmental Information (NCEI) U.S. Billion-Dollar Weather and Climate Disasters (2025). <https://www.ncei.noaa.gov/access/billions/>, DOI: 10.25921/stkw-7w73

There are long-term tide gauge measurements at Grand Isle, Louisiana, respectively estimating that sea level has risen slightly more than 3 feet over the last 100 years and at an average rate of 0.36 inches/year (Figure 8.3). Vertical land motion (subsidence) is estimated -0.28 inches/year at Grand Isle. From Table 6.1, the absolute sea level rise is +0.08 inches/year at Grand Isle.

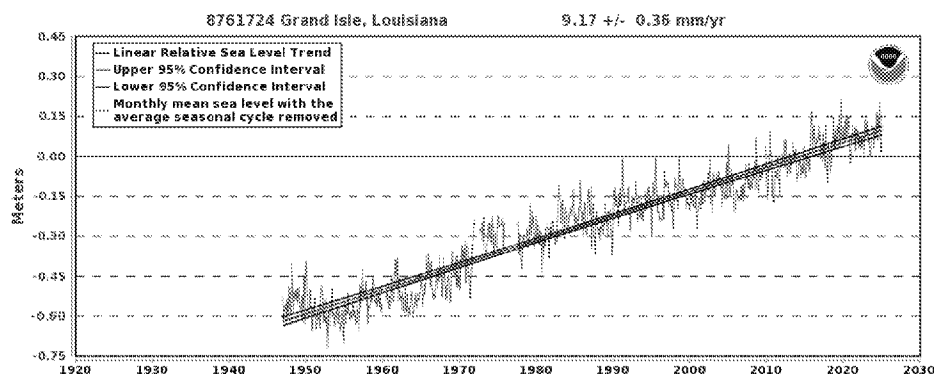


Figure 8.3. Tide gauge measurements at Grand Isle, LA, obtained from NOAA - https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=8761724 (downloaded 4/22/25).

The issues of sea level rise and land loss in the Mississippi delta region are complex, with geological subsidence and the decline in sediment transported by the Mississippi river being the dominant drivers. Due to the construction of dams in the basin since the 1950s, the suspended sediment load of the Mississippi River has decreased by ~50%.¹¹ A new subsidence map of coastal Louisiana finds the coastal region to be sinking at about one third of an inch per year.¹² For a city whose elevation averages one to two feet below sea level, sea level rise from human caused warming is not the dominant driver for the problems that New Orleans is facing.

New York City

New York City is particularly vulnerable to the effects of sea level rise because it is built primarily on islands and has 520 miles of coastline. In New York City, relative sea level has risen over 11 inches over the past century, at an average rate of 0.11 inches/year (Figure 8.4). Vertical land motion in the New York City area is occurring at a rate of -0.05 inches/year (subsidence), corresponding to roughly 5 inches per century. From Table 6.1, the absolute rate of sea level rise at The Battery location is 0.06 inches/year, or about 55% of the measured relative sea level rise.

¹¹ Jillian M. Maloney et al., "Mississippi River Subaqueous Delta Is Entering a Stage of Retrogradation," *Marine Geology* 400 (June 2018): 12–23, <https://doi.org/10.1016/j.margeo.2018.03.001>.

¹² Jaap H. Nienhuis et al., "A New Subsidence Map for Coastal Louisiana," *GSA Today* 27, no. 6 (June 2017): 28–29, <https://doi.org/10.1130/GSATG337GW.1>.

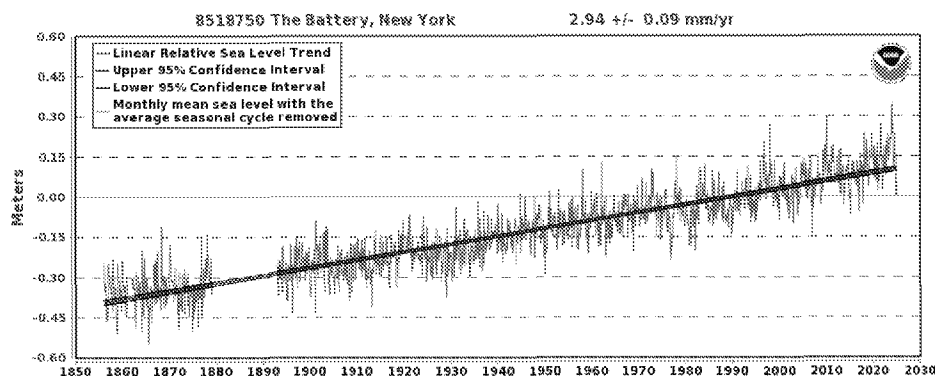


Figure 8.4. Tide gauge measurements at The Battery, New York, obtained from NOAA - https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=8518750 (downloaded 4/22/25).

Following Hurricane Sandy, New York has developed a comprehensive plan: [[HYPERLINK "http://s-media.nyc.gov/agencies/sirr/SIRR_singles_Hi_res.pdf"](http://s-media.nyc.gov/agencies/sirr/SIRR_singles_Hi_res.pdf)].¹³ A broad range of coastal protection measures are outlined that match the risks facing a given area: increase coastal edge elevations, minimize upland wave zones, infrastructure to protect against storm surge, improve coastal design and governance, restore estuaries wetlands, coastal nourishment, site elevation, and drainage systems.

9.2. Sea level rise projections

The concern over sea level rise is not about the 8 inches or so that global mean sea level has risen since 1900. Rather, the concern is about projections of 21st century sea level rise based on climate model-based projections of human-caused global warming.

The IPCC AR6 finds that there is high agreement across published global mean sea level projections for 2050 and there is little sensitivity to emissions scenarios. Considering only projections incorporating ice-sheet processes in whose quantification there is at least medium confidence, the global sea level projections for 2050, across all emissions scenarios, fall between 3.94 and 15.75 inches (5th–95th percentile very likely range) relative to the 1995–2014 baseline period.

Conversely, there is low agreement across published global mean sea level projections for 2100, particularly for higher emissions scenarios. Considering only projections representing processes in whose quantification there is at least medium confidence, the AR6 global mean sea level projections for 2100 lie between 7.87 and 39.37 inches (5th–95th percentile very likely range) under the medium

¹³ City of New York, *A Stronger, More Resilient New York* (New York: City of New York, June 2013), http://s-media.nyc.gov/agencies/sirr/SIRR_singles_Hi_res.pdf.

emissions scenario SSP2-4.5. There is deep uncertainty surrounding projections of sea level rise to 2100, particularly for the higher emissions scenarios.

In evaluating the IPCC AR6 projections to 2050 (with reference to the baseline period 1995-2014), almost half of the sea level rise has already occurred by 2025. From the tide gauge measurements in Figures 8.1-8.4, there is no obvious acceleration in sea level rise beyond the historical average rate of sea level rise.

9.3. Summary

Since 1900, global sea level has risen by about 8". Sea level change along U.S. coasts is highly variable, associated with local variations in processes that contribute to sinking and also ocean circulation patterns. The highest levels of sea level rise along U.S. coasts are Galveston, New Orleans, and the Chesapeake Bay regions. Each of these locations is associated with substantial local sinking that is unrelated to climate change.

Extreme projections of global sea level rise are associated with the implausible extreme emissions scenario and inclusion of poorly understood processes associated with hypothesized ice sheet instabilities. In evaluating the IPCC AR6 projections to 2050 (with reference to the baseline period 1995-2014), almost half of the sea level rise has already occurred by 2025 and at a lower rate than predicted. From the tide gauge measurements in Figures 8.1-8.4, there is no obvious acceleration in sea level rise beyond the historical average rate of sea level rise.

Part III: Impacts on Ecosystems and Society

10. Climate change and US agriculture

10.1. Econometric analyses

Econometric analyses of the effects of climate change on agriculture have sought to integrate information about long term crop yield changes in response to temperature and precipitation changes under assumptions about adaptive behavior by farmers. One method focuses on variations in agricultural land values. The rationale is that if climate change is a long-term net benefit for agriculture it should translate into higher market values for agricultural land, and vice versa. While individual crops might benefit from or be harmed by climate change, once the adaptive responses of farmers are taken into account the value of farmland represents an index of whether the changes are expected to be beneficial or not. Mendelsohn et al. (1994) examined the relationship between historical climatic variations on agricultural land values and concluded global warming would be slightly beneficial to American agriculture.

The Mendelsohn et al. method, called Ricardian analysis after David Ricardo, the 19th century British economist who pioneered the study of land values, attracted subsequent criticism from authors who argued it failed to account for differences in land values attributable to fixed locational characteristics like soil quality, and non-climatic changes including nearby urbanization. Deschênes and Greenstone (2007) looked at agricultural profits instead of land values and reached similar conclusions to Mendelsohn et al. (1994), namely that past climatic variations had relatively little effect on farm profitability and that warming would likely yield small overall benefits for the US agricultural sector. However a subsequent exchange with critics led them (Deschênes and Greenstone 2012) to revise their conclusions and project potentially large losses in US agriculture due to climate warming. Burke and Emerick (2016) looked at temperature variations over 1980 to 2000 and argued that farmers were not as able to adapt to temperature changes as the Ricardian method assumes and that climate change would have large negative impacts on corn and soy yields. Schlenker and Roberts (2009) similarly argued that yield gains to past warming would not carry over to the future and corn and soy yields would sharply decrease this century due to climate change.

Two recent studies have argued that pessimistic findings such as these are not robust. Criz-Bohea (2019) argued that land values aggregate farm and non-farm influences and the latter need to be filtered out. He developed a data set using cash rents for agricultural activity as a measure of land value specifically for farming activity. Whereas the land value model implied future losses under climate warming, the same model estimated using cash rents did not, leading the author to conclude the pessimistic results were due to using an inaccurate measure of the returns to farming activity. Bareille and Chakir (2023) assembled a large data base on farm sale prices in France for properties that sold twice between 1996 and 2019. They could replicate pessimistic results showing negative effects of warming on agricultural land values using conventional econometric modeling. But by taking advantage of the repeat sales data, which provides information on site-specific changes in land prices, they found the results reversed and implied that climate change will be very beneficial for French agriculture. The authors concluded that, taking adaptation into account, a warming climate would yield positive benefits for French agriculture that were between two and 20 times larger than had previously

been estimated. On average, with full adaptation, they concluded that climate changes under the medium RCP4.5 scenario could double the value of French farmland by 2100.

A major deficiency of all these studies, however, is that they omit the role of CO₂ fertilization. Climate change as it relates to this report is caused by GHG emissions, chiefly CO₂. The econometric analyses referenced above focus only on temperature and precipitation changes and do not take account of the beneficial growth effect of the additional CO₂ that drives them. As explained in Chapter 2 CO₂ is a major driver of plant growth so this omission biases the analysis towards underestimation of the benefits of climate change on agriculture.

10.2. Field studies of CO₂ enrichment

One of the ways the effect of CO₂ on crop growth has been studied is through “free air enrichment experiment” or FACE plots, in which small chimneys are placed in fields surrounding plants and the growth response to elevated CO₂ under varying weather conditions are recorded. Ainsworth et al. (2020) summarizes results from about 250 such studies. They found that elevation of CO₂ by 200 ppm cause an average 18% increase in crop yield in C3 plants. C4 plants exhibited benefits mainly under drought conditions.

In addition to FACE plot experiments there have been thousands of laboratory experiments on the effects of CO₂ on all kinds of plant growth. Here we review some of the results on key US agricultural crops.

Soybean

Studies on the impact of elevated CO₂ on Soybean (*Glycine max* (L.) Merr.) plants in the water-deficient region of Huang-Huai-Hai Plain, China, showed that elevated CO₂ concentrations resulted in improved photosynthesis rate, water use efficiency and growth (Li, 2013) under both normal conditions and drought conditions. The CO₂Science.org website reports on 108 published experiments between 1985 and 2019 exposing soybean to enriched CO₂ levels. Converted to a +300ppm common scale the average growth benefit was +50.9 percent. In addition there were 10 studies reporting on +600 ppm CO₂ enrichment, resulting in an average increase in photosynthesis of 90.3%.

Maize (corn)

The CO₂Science.org website reports on 28 published experiments between 1983 and 2018 exposing corn (*Zea mays* L.) to enriched CO₂ levels. Converted to a +300ppm common scale the average growth benefit was +23.7 percent. Corn also benefits from increased drought tolerance under elevated CO₂. An experimental study (Allen Jr, 2011) exposed plants to water stress conditions in sunlit controlled-environment chambers at 360 ppm (ambient) and 720 ppm (elevated) CO₂. The drought stress caused a 41% loss of growth under ambient CO₂ but only a 13% loss under elevated CO₂.

Wheat

The CO2Science.org website reports on 92 published experiments between 1983 and 2020 exposing common wheat (*Triticum aestivum* L.) to enriched CO₂ levels. Converted to a +300ppm common scale the average growth benefit was +67.6 percent. Blandino (2020) measured the yield as well as nutritional quality of an “improver” hybrid wheat variety and its parents under elevated CO₂ levels (+166 ppm). They reported a grain yield increase of +16% but a 7% decrease in grain protein levels. But they found that the food quality of different wheat varieties responded differently to elevated CO₂ levels, so that with proper varietal selection end-users can select wheat types that best take advantage of the elevated CO₂.

Further evidence

A 2021 report from the US National Bureau of Economic Research (Taylor and Schlenker 2021) used satellite-measured observations of outdoor CO₂ levels across the United States, matched to county-level agricultural output data and other economic variables. After controlling for the effects of weather, pollution and technology the authors concluded that CO₂ emissions had boosted US crop production since 1940 by 50 to 80 percent, attributing much larger gains than had previously been estimated using FACE experiments. They found that every ppm of increase in CO₂ concentration boosts corn yields by 0.5 percent, soybeans by 0.6 percent, and wheat by 0.8 percent.

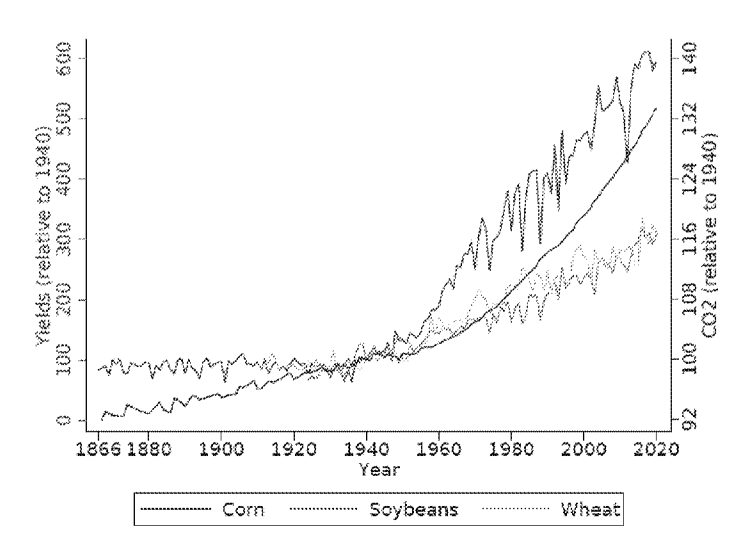


Figure 10.1: US average CO₂ levels and yields of corn, soy and wheat all normalized so 1940=100. Source: Taylor and Schlenker (2021)

Beyond growth benefits, extra CO₂ boosts plant resilience to heat. Deryng et al. (2016) surveyed all available evidence regarding how wheat, maize, rice and soybean will grow under a combination of climate warming and rising CO₂ levels. They concluded that warming would, eventually, have a negative effect on plant growth but it would be fully compensated by the extra CO₂ for wheat and soybean, and almost fully for rice and maize. And as discussed in Chapter 2, plants use water more efficiently when there is more CO₂ in the air.

Deryng et al. (2016) surveyed evidence on crop water productivity (CWP), i.e. yield per unit of water used, drawing attention to the potential for CO₂ both to enhance photosynthesis and reduce leaf-level transpiration (water loss during leaf respiration). They surveyed all available FACE data on crop yield changes for Maize (corn), Wheat, Rice and Soybean, and combined it with crop model data simulating yield responses as of 2080 under the extreme RCP8.5 scenario in four growing regions (Tropics, Arid, Temperate and Cdd) each of which were split into rainfed and irrigated sub-regions. In every region they reported that models without CO₂ fertilization predicted CWP losses but CO₂ fertilization more than offset them and once it was taken into account all regions showed a net CWP gain. Deryng et al. (2016) also reported that negative impacts on wheat and soybean yields were fully offset by CWP gains, and mitigated by up to 90% for rice and 60% for maize.

Similar to this, Cheng et al. (2017) noted that increased global plant growth from 1982 to 2011 due to rising CO₂ uptake was accompanied by such large gains in CWP that despite the extra biomass global water use by plants had not increased.

Deryng et al. (2016) assumed that climate change would “exacerbate water scarcity”. It is noteworthy that while models predict drylands will expand under climate warming, current data show the opposite: greening is happening even in arid areas. Zhang et al. (2014) report that due to increased CO₂ levels “increasing aridity in drylands won’t lead to a general loss of vegetation productivity”; increased desertification will happen in at most 4% of currently arid areas.

10.3. Crop modeling meta-analyses

Notwithstanding the abundant evidence for the direct benefits of CO₂ and of CO₂-induced warming on crop growth, in 2023 the US Environmental Protection Agency (EPA 2023) boosted its estimate of the Social Cost of Carbon (SCC) about five-fold based in large part on a very pessimistic 2017 estimate of global agricultural damages from climate warming (Mbore et al., 2017). One of the two damage models used by the EPA attributed nearly half of the 2030 SCC to projected global agricultural damages based on the Mbore et al. (2017) analysis. This study was a meta-analysis of crop model studies simulating yield changes for agricultural crops under various climate warming scenarios. Mbore et al. projected declining global crop yields for all crop types in all regions due to warming.

McKittrick (2025) re-examined the Mbore et al. database and found that, while it claimed to cover 1,722 studies, only half the entries ($N=862$) had complete records, so that the sample available

for regression analysis was much smaller than both studies indicated. McKittrick noted that the variable most commonly missing was the change in ambient CO_2 and found that in many cases these could be recovered from the underlying studies or the original climate scenario tables. He thereby increased the usable sample size by 40 percent. The crop yield projections incorporating the newly available data changed considerably. As shown in Figure 10.2, whereas the partial data set implied warming would decrease yield (blue lines), the complete data set implied constant or increase global yields, even out to 5°C warming (green lines).

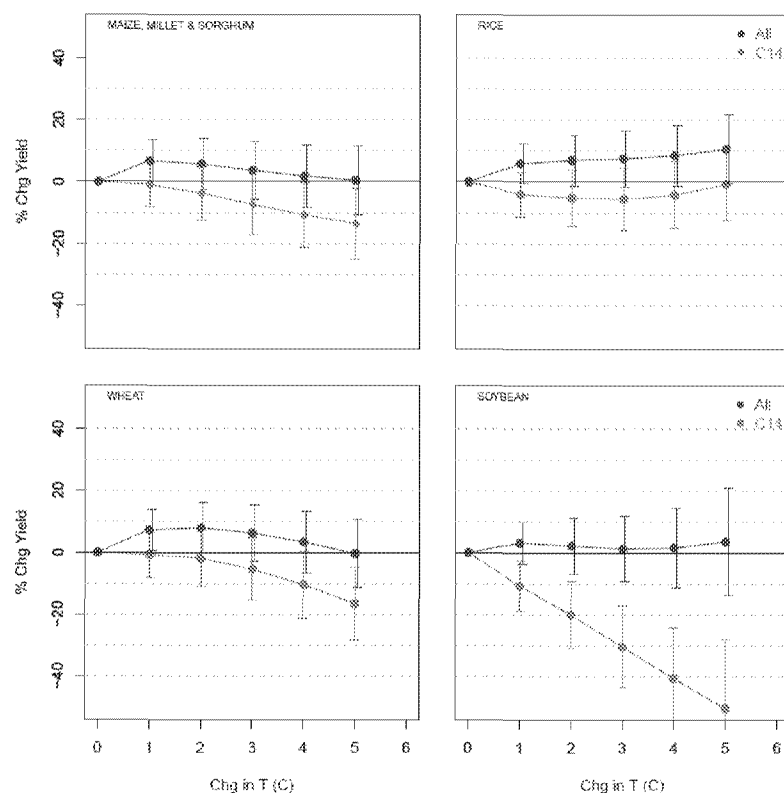


Figure 10.2 Crop yields under CO_2 -induced climate warming. Blue: as published in Moore et al. (2017). Green: after including omitted data. Source: McKittrick (2025).

In summary, there is abundant evidence going back decades that rising CO_2 levels benefit plants including agricultural crops, and that CO_2 -induced warming will be a net benefit to US agriculture. The warming since 1981, in combination with adaptive behaviour by farmers, has been beneficial on its own for maize. The increased ambient CO_2 has also boosted productivity

of all major US crop types. Various attempts to argue that CO₂-induced warming will harm agriculture do not hold up under scrutiny.

Deschênes, Olivier and Michael Greenstone (2007) The Economic Impacts of Climate Change: Evidence from Agricultural Output and Random Fluctuations in Weather *American Economic Review*. Feb 2007, Vol. 97, No. 1: Pages 354-385

Deschênes, Olivier and Michael Greenstone (2012) The Economic Impacts of Climate Change: Evidence from Agricultural Output and Random Fluctuations in Weather: Reply to Comment *American Economic Review*. 102, no. 7: 3761-3773. [[HYPERLINK "http://hdl.handle.net/1721.1/82641"](http://hdl.handle.net/1721.1/82641)]

Ortiz-Bobea, Ariel (2019) The role of nonfarm influences in ricardian estimates of climate change impacts on US agriculture. *American Journal of Agricultural Economics*. 102 (3), 934–959.

Schlenker, Wolfram and Michael Roberts (2009) Nonlinear temperature effects indicate severe damages to U.S. crop yields under climate change. *Proceedings of the National Academy of Sciences* 106 (37) 15594-15598 [[HYPERLINK "https://doi.org/10.1073/pnas.0906865106"](https://doi.org/10.1073/pnas.0906865106)]

11. Managing risks of extreme weather

11.1. Socioeconomic context

Risks from human-caused climate change are convoluted with natural weather and climate variability, and are dominated by the exposure of wealth in coastal and other disaster-prone regions and vulnerabilities of poorer populations. The evolution of climate risk in the U.S. has been dominated by societal factors, rather than by changes to the actual weather and climate hazards. Deaths from weather disasters have decreased substantially since 1900, even as US population grew from 76 million in 1900 to over 331 million in 2020. For example, the Galveston hurricane killed over 8,000 people in 1900 (0.01% of the US population), whereas the worst recent disaster, Hurricane Katrina in 2005, killed 1800 people (or 0.0006% of the US population).

Technological advances have substantially reduced losses from extreme weather events. Early warning systems, satellite monitoring, and improved weather forecasting have reduced deaths, although exactly numbers are hard to quantify. [HYPERLINK "<https://www.nber.org/papers/w31361>"]

US weather forecasting has been estimated to reduce losses from weather events with an annualized benefit of \$31.5B, protecting lives, property, and supporting agriculture and transportation [HYPERLINK "<https://nap.nationalacademies.org/read/12888/chapter/2>"] Improved hurricane forecasts have reduced pre- and post-landfall spending, with annual per hurricane cost reductions estimated at \$5B

[HYPERLINK "<https://www.nber.org/digest/202409/value-improving-hurricane-forecasts>"]

Infrastructure improvements have contributed to substantial reductions in losses from extreme weather events. Building codes, such as those implemented in Florida after Hurricane Andrew (1992) have reduced losses by ensuring structures can withstand high winds and floods. Homes built after 2002 showed minimal damage during Hurricane Michael (2018), unlike older homes.

[HYPERLINK "<https://www.fema.gov/case-study/role-floridas-building-codes-2018-hurricane-michael>"]. Sea walls, like the Galveston Seawall, protect against wave action and storm surge. The New Orleans Hurricane and Storm Damage Risk Reduction System successfully mitigated storm surge during Hurricane Isaac (2012). Flood dams in the US help control flooding by storing excess water during heavy rains. It is estimated that the Tennessee Valley Authority (TVA) dams prevent about \$309M in annual flood damage in the TVA region and along the Ohio and Mississippi Rivers [HYPERLINK "<https://www.tva.com/environment/managing-the-river/flood-management>"]

During Hurricane Helene (2024), TVA's strategies prevented approximately \$406M in potential damages. [HYPERLINK "<https://www.publicpower.org/periodical/article/tva-flood-mitigation-strategies-prevented-approximately-406-million-potential-damages>"]

11.2. Data challenges

Since 1980, NOAA has provided a count of annual U.S. weather-related disasters that it estimates to have exceeded \$1Billion (inflation adjusted), showing a substantial increase starting in 2008. NOAA and other government officials have cited the upward trend in the BDD series as evidence that climate change is making extreme weather worse (Pelke Jr. 2024). But over time, population and wealth have increased dramatically in the US, so when an extreme weather or climate event occurs, there is more damage even if there is no underlying trend in the frequency or intensity of extreme weather. A recent estimate finds that losses per weather disaster are down by about 80% since 1980, as a proportion of GDP.

[HYPERLINK

"<https://drive.google.com/file/d/1MvgwcVaimcn1oHODqNZDG1fXF4M5Idnn/view>"]

Pelke Jr. (2024) argued that in addition to relying on opaque data sources and unreported adjustments NOAA failed to normalize its Billion Dollar Disaster (BDD) data series properly for changes in population exposure and wealth. In May 2025 NOAA announced it has withdrawn the billion dollar disaster product from publication (Pelke Jr. 2025).

In summary, trends in losses from extreme weather and climate events are dominated by population increases and economic growth. Technological advances such as improved weather forecasting and early warning systems have substantially reduced losses from extreme weather events. Better building codes, flood defenses, and disaster response mechanisms have lowered economic losses relative to GDP. And finally, the US economy's expansion has diluted the relative impact of disaster costs, as seen in the comparison of historical and modern GDP percentages.

Pelke Jr., Roger (2024) Scientific integrity and U.S. "Billion Dollar Disasters" *NPJ Natural Hazards* 1 [HYPERLINK "<https://www.nature.com/articles/s44304-024-00011-0>"]

Pelke Jr., Roger (2025) "RIP NOAA's Billion Dollar Disasters" Substack essay May 8, 2025 [HYPERLINK "<https://rogerpielkejr.substack.com/p/rip-noaas-billion-dollar-disasters>"]

12. Mortality from temperature extremes

12.1. Heat and cold risks

Changes in temperature extremes are among the most certain impacts expected in a warming globe -- extreme heat events are expected to become more frequent while extreme cold events become less frequent. This pattern is evident in the historical period (as discussed in Section XX) and is expected to intensify with continued warming.

Mortality during heat extremes is typically caused by heat stroke and heat exhaustion, while mortality during cold extremes is typically caused by hypothermia and heart strain. It is well known that global mortality is substantially greater for extreme cold than for extreme heat.^{14,15}

Specific to the U.S., extreme heat and extreme cold both kill hundreds of people each year; however, different approaches to assessing heat/cold mortality produces different results. The Center for Disease Control (CDC) National Center for Health Statistics Compressed Mortality Database, which is based on death certificates, indicates that about twice as many people die of "excessive cold" conditions in a given year than of "excessive heat."^{16,17}

A 2015 epidemiological study of deaths in published in *The Lancet* found that cold-related deaths in the U.S. were about a factor of fifteen higher than heat-related deaths.¹⁸ However, the study did not adjust for the seasonal cycle in mortality rates, which tend to increase during the winter months due to non-weather factors like influenza.¹⁹ A more recent paper found that 86% of temperature-related deaths in the U.S. are due to cold-related mortality.²⁰

¹⁴ Qi Zhao et al., "Global, Regional, and National Burden of Mortality Associated with Non-Optimal Ambient Temperatures from 2000 to 2019: A Three-Stage Modelling Study," *The Lancet Planetary Health* 5, no. 7 (July 2021), [https://doi.org/10.1016/s2542-5196\(21\)00081-4](https://doi.org/10.1016/s2542-5196(21)00081-4).

¹⁵ <https://ourworldindata.org/part-one-how-many-people-die-from-extreme-temperatures-and-how-could-this-change-in-the-future>

¹⁶ Brett R. Scheffers et al., "The Broad Footprint of Climate Change from Genes to Biomes to People," *Science* 354, no. 6313 (November 11, 2016): aaf7671, <https://doi.org/10.1126/science.aaf7671>.

¹⁷ Rachel H. Alinsky, Scott E. Hadland, J. Deanna Wilson, Pamela A. Matson, and Brendan Saloner, "Trends in Polysubstance Overdose Deaths Involving Opioids, Stimulants, and Benzodiazepines by Race and Ethnicity in the US, 2007-2021," *JAMA Network Open* 7, no. 3 (March 2024): e238249, <https://doi.org/10.1001/jamanetworkopen.2024.8249>.

¹⁸ Lancet Commission on Climate and Health, "Health and Climate Change: Policy Responses to Protect Public Health," *The Lancet* 386, no. 10006 (November 7, 2015): 1861-1914, [https://doi.org/10.1016/S0140-6736\(15\)60854-6](https://doi.org/10.1016/S0140-6736(15)60854-6).

¹⁹ Bob Henson, "Which Kills More People: Extreme Heat or Extreme Cold?" *Weather Underground*, January 22, 2019, <https://www.wunderground.com/cat6/Which-Kills-More-People-Extreme-Heat-or-Extreme-Cold>.

²⁰ Tarik Benmarhnia et al., "Deaths Attributable to Heat and Cold: Comparison of Data Sources and Evaluation of Inconsistencies," *GeoHealth* 8, no. 3 (March 2024): e2023GH000799, <https://doi.org/10.1029/2023GH000799>.

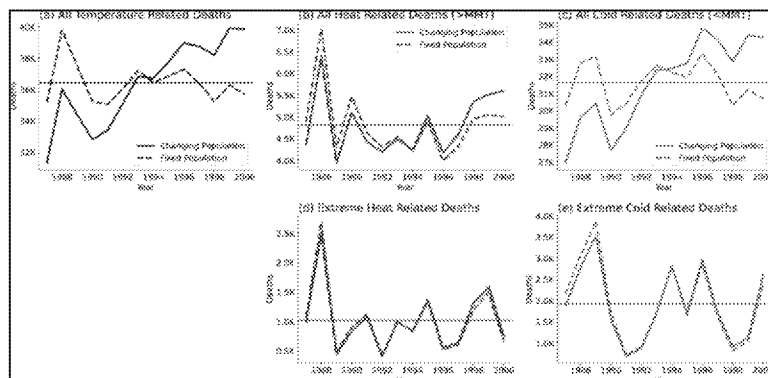


Figure 12.1: Time series of temperature-related deaths across all 106 cities. (a) The solid line represents total temperature-related deaths, while the dashed line indicates temperature-related deaths with a fixed population (average population from the 1987–2000 period). (b) Similar to (a), but for heat-related deaths. (c) Similar to (a), but for cold-related deaths. (d) Time series of deaths occurring in temperatures above the 97.5th percentile. (e) Similar to (d), but for temperatures below the 2.5th percentile. From <https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2023GH000799>

The IPCC AR6 Working Group 2 Chapter 16.2.3.5 states how heat-related mortality is declining over time:²¹

“Heat-attributable mortality fractions have declined over time in most countries owing to general improvements in health care systems, increasing prevalence of residential air conditioning, and behavioral changes. These factors, which determine the susceptibility of the population to heat, have predominated over the influence of temperature change.”

A 2011 study of 40 major US cities between 1975 and 2004, found that heat wave mortality had decreased, in spite of rising temperatures, due to adaptation.²² Likewise Davis et al. (2003) examined heat-related mortality in 28 U.S. cities from the 1960s to the end of the 1990s and found that heat-related mortality declined by three-quarters over the sample period. Bobb et al. (2014) examined mortality data for 106 million people in over 100 cities U.S. cities and found a 60% decline in average heat-related mortality over the period 1987–2005, from 51 per thousand deaths to 19. They furthermore found that the greatest drop was among seniors over

²¹ B. O'Neill et al., “Key Risks Across Sectors and Regions,” in *Climate Change 2022: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (Geneva, CH: Intergovernmental Panel on Climate Change, 2021), 2411–2538.

²² Keith T. Ingram, Carolyn W. Furman, and John W. Jones, “Climate Change Impact and Adaptation Assessment: A Guide for Coastal Resources Managers,” *Weather, Climate, and Society* 3, no. 4 (October 2011): 234–249, <https://doi.org/10.1175/WCAS-D-11-00055.1>.

the age of 75. In a study of 42 million deaths in 211 U.S. cities from 1962 to 2006, Nordio et al. (2015) found a more than 90 percent decline in the risk of mortality from excess heat.

In the context of large declines in heat-related mortality, by reducing mortality from cold events rising temperatures are associated with a net saving of lives.

It is both disappointing and telling to see how the IPCC misrepresents the situation in its AR6 Synthesis report. Section A.2.5 of that document states: "In all regions increases in extreme heat events have resulted in human mortality and morbidity (*very high confidence*)."

But it is silent on the larger decline of deaths during extreme cold events.

12.2. The importance of adaptation

The observed decline in US heat-related mortality has been specifically attributed to adaptation. Wang et al. (2018) exploited the spatial variability of heatwave-related mortality across 209 U.S. cities from 1962 to 2006. While simple correlation appeared to imply an increase in mortality risk during heatwaves, accounting for adaptation to heatwave intensity caused the effect to fall to near zero and become statistically insignificant. They used the results of their epidemiological model to project heat-related mortality out to 2050 under four RCP warming scenarios (including RCP8.5) with and without adaptive behavior. Assuming people continue to adapt to the heatwave risks in the regions in which they live Wang et al. project not only no increase in heat-related mortality but an overall decrease for the US as a whole. They conclude that "Ignoring adaptation would result in a substantial overestimate of future mortality related to heat waves... Accounting for adaptation, the overall heat-related mortality by 2050 would not change substantially over time compared to 2006."

12.3. Mortality risks and energy costs

A 2016 study of US long term mortality risks associated with temperature variations (Barreca et al. 2016) showed that increases in mortality across the US are associated both with cold weather and hot weather. But over time, the introduction of electricity and the adoption of central heating and air conditioning (AC) dramatically reduced both risks, especially those associated with hot weather. Prior to 1960, a day above 90°F (32°C) added 2.2 percent to the average mortality risk rate, but after 1960 the same weather added only 0.3 percent to mortality risk, an 85 percent reduction. Prior to 1960 temperatures below 39°F (4°C) added about 1 percent to mortality risk but after 1960 the same weather only added about half that amount. Adaptation through conventional household improvements dramatically reduced public vulnerability to weather extremes. The entire reduction in hot weather mortality was attributable to widespread adoption of indoor AC, which depended on the availability of reliable and affordable electricity.

The corollary of this finding is that the use of heating and cooling systems depends on energy being affordable. Doremus et al. (2022) showed that wealthy and poor households in the US adjust their energy expenditures at similar rates in response to moderate temperature swings, but not in response to extreme temperature swings. When temperatures swing to very cold levels (< 5°C) energy spending in high-income households rises by 1.2 percent but in low-income households by only 0.5 percent. On very hot days (>30°C) electricity spending in high-income households rises by 0.5 percent but does not change at all in low-income households.

The latter result is observed even in subsamples where all households have AC. The implication is that even with widespread adoption of home heating and cooling systems, inability to afford energy leaves low-income households exposed to weather extremes.

Barreca, Alan, Karen Clay, Olivier Deschenes, Michael Greenstone, and Joseph S Shapiro, "Adapting to climate change: The remarkable decline in the US temperature mortality relationship over the twentieth century," *Journal of Political Economy*, 2016, 124 (1), 105–159.

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13. Climate change, the economy and the Social Cost of Carbon

13.1. Climate change and economic growth

13.1.1 Overview: climate is a relatively minor issue for a modern economy

It has long been noted that economies tend to do poorly in very cold and very hot regions, with the optimum somewhere in between (Nordhaus 2006). Temperature-sensitive economic activity migrates, whenever possible, to where it is best suited, and society always adapts to the local climate. Based in part on these observations, in 1992 Thomas Schelling, then President of the American Economic Association, argued that any effects climate change on US economic activity would be small relative to the many other changes that would happen.

Commented [SK16]: This material is great, but it stands out as much more comprehensive and detailed than almost anything else we're written. Do we keep it or try to thin it down?

... Manufacturing rarely depends on climate, and where temperature and humidity used to make a difference, air conditioning has intervened. When Toyota chooses among Ohio, Alabama, and Southern California for locating an automobile assembly, geographical considerations are important, but not because of climate... Finance is little affected by climate; similarly for health care, or education, or broadcasting.

Transportation can be affected, but improvements in all-weather landing and take-off in the last 30 years are greater than any differences that climate makes. If the average effect is a warming, iced waterways and snow removal may decline in importance. Construction is affected, mainly by cold, and if the average effect is in the direction of warming, construction may benefit slightly.

It is really agriculture that is affected. But even if agricultural productivity declined by a third over the next half century, the per capita GNP we might have achieved by 2050 we would achieve only in 2051. ...

I conclude that in the United States, and probably Japan, Western Europe, and other developed countries, the impact on economic output will be negligible and unlikely to be noticed.

(Schelling 1992, emphasis added)

Thirty years later virtually the identical point was made by the IPCC itself in the Fifth Assessment Report:

For most economic sectors, the impact of climate change will be small relative to the impacts of other drivers. Changes in population, age, income, technology, relative prices, lifestyle, regulation, governance, and many other aspects of socioeconomic development will have an impact on the supply and demand of economic goods and services that is large relative to the impact of climate change.

(Arent et al. 2014, emphasis added)

That statement is validated by experience. Since 1900, the average global surface temperature anomaly warmed 1.3°C, about as much as the IPCC predicts will occur in the next century under a moderate emissions scenario. But even as the globe warmed and the population quintupled, humanity prospered as never before. For example, global average lifespan went from thirty-two years to seventy-two years, economic activity per capita grew by a factor of seven, and the death rate from extreme weather events plummeted by a factor of fifty!

While extreme weather events are costly, in all modern economies they are becoming steadily less and less important (Formetta and Feyen 2019). Since 1990 weather-related disaster losses have declined as a proportion of global GDP (Pelke Jr 2018, 2020) as have mortality risks (Formetta and Feyen 2019). While economic weather-related insurance payouts are rising, this is fully explained by the growth in the size of the economy and the value of the insured asset stock. Past increases in episodes extreme weather have not had a significant effect (positive or negative) on the market value of insurance firms (Hu and McKittrick 2015). Nor have past extreme weather events had a significant effect on US banks' performance (Blickle et al. 2021).

For these reasons, economists have long been reluctant to endorse attempts to "stop" climate change or even aggressively reduce GHG emissions because the costs would not be worth it. As one critic of the economics of climate policy put it:

Mainstream climate economics takes global warming seriously, but perplexingly concludes that the optimal economic policy is to almost do nothing about it... The contrast is striking. While climate science is sending out loud-and-clear messages that fossil-fuel disinvestment must start now, letting go of coal and oil and diverting resources into renewable energy technology systems, to keep warming below the 2°C limit (IPCC 2014), mainstream climate economics claims that overly ambitious climate targets will unnecessarily hurt the economy and immediate de-carbonization is too expensive. Most climate economists thus recommend humanity to just wait-and-see.

(Storm 2017)

The mainstream economics position on the climate policy question is best represented by the findings over the past three decades from Integrated Assessment Models (IAMs) of climate change policy, for which Yale economist William Nordhaus was awarded the 2018 Nobel Memorial Prize in economics. IAMs combine economic, climate, and social data into a unified framework for simulating climate damages and evaluating the optimal policy response (Resources for the Future 2025). Nordhaus' work has generally supported modest global climate policy, with aggressive measures largely deferred to later in the century. Nordhaus developed the so-called Dynamic Integrated Model of the Climate and Economy model, or DICE, in the early 1990s (Nordhaus 1993) to study the interaction between climate change, climate policy, and global economic growth over long times. DICE assumes global emission control can be coordinated at no cost and asks what the optimal policy target should be. The climate component of the DICE model is based on simplified climatological modeling. The version of DICE at the time of Nordhaus' Nobel Prize award was described in Nordhaus (2018); it had a climate sensitivity parameter of 3.1°C for CO₂ doubling, consistent with the best estimate in contemporary IPCC reports (3.0°C).

The baseline (no policy) scenario incurs only \$0.4T in global abatement costs and leads to \$134.2T (trillion dollars) in global climate damages for a total cost of \$134.6T. The climate model component of DICE projects 4.1°C warming by 2100 relative to preindustrial temperatures. Note that this is a higher estimate of warming than many PCC climate models. (AR6 offers 2.7°C in 2100 under a moderate emissions scenario.)

Commented [SK17]: Check this

The Optimal Policy scenario barely deviates from the business-as-usual path. It aims for +3.5°C warming, in other words we scale back only the lowest-value fossil fuel use and otherwise just live with almost all the warming. This suggests that most CO₂ emissions are less harmful than the policies that would be necessary to abate them. Trying to prevent warming causes costs quickly to outstrip the benefits. Pursuing a goal of capping warming at 2.5°C creates total costs of \$177.8T, which is \$43.2T worse than doing nothing at all. Nordhaus didn't evaluate trying to reach a Paris-type target of 1.5°C warming but it would be even worse.

Commented [SK18]: Don't understand this phrase. "we minimally cut back on fossil fuel use"?

A subsequent edition of DICE includes higher assumed damages from warming which, not surprisingly leads to more aggressive policy recommendations, as explained in the section below on the Social Cost of Carbon.

Commented [SK19]: My understanding is that much depends upon the discount rate assumed. If that's true, what did Nordhaus take for that? And has that value been challenged subsequently?

13.1.2 Empirical analysis of climate change and economic growth

Many other studies have used econometric methods instead of IAMs to look at the potential impact of climate change on economic growth. Dell et al. (2012, herein DJO12) was an influential study that used a multi-country panel of national-level data spanning 1950 to 2005, in which they matched climate and economic data by averaging temperature from the local grid cell level up to the national level using population weights. They found that warming yields an insignificant positive effect on income growth in rich countries but a significant negative effect in poor countries. Moore and Diaz (2015) modified the DICE model to take that finding into account and concluded that it implied a dramatically higher Social Cost of Carbon due to the compounding effects of income loss over time.

A large subsequent literature has debated the robustness of the DJO12 findings. Burke et al. (2015) analyzed a global panel with temperatures averaged up to the national level and found a negative effect on growth from warming in rich and poor countries alike when the national average temperature is above 13°C. Zhao et al. (2018) used the G-Econ data set of Nordhaus (2006), which breaks economic activity down to the grid cell level, replicated DJO12-type results on the same subset of countries as used in DJO12 but then showed that on the full global sample warming increases growth in rich countries and poor countries alike, though the positive effect in the latter group is confined to where local temperatures are below about 16°C. Greßer et al. (2021) developed a regional economic data set for 1,542 sub-national regions around the world between 2005 and 2015 and found temperature had no effect on growth. Yang et al. (2023) updated the DJO12 data set and applied an estimator robust to mixed sample frequencies, finding that while temperature shocks exerted a temporary effect on income levels, they did not have a significant lasting effect on growth rates.

Newell et al. (2021) noted that there is no underlying theory to guide econometric model specification in this literature. Taking into account the arbitrary choices of which explanatory

variables to include they identified over 800 possible model specifications. Using the Burke et al. (2015) data they used an estimation method that accounts for model uncertainty and found that the model form preferred by Burke et al. (2015), which implied negative effects of warming on growth even in rich countries, is explicitly excluded by the optimal model selection algorithm. Overall they could not detect a temperature effect on GDP or GDP growth, and they estimated the 95% confidence interval for the impact on global growth as of 2100 even under the exaggerated RCP8.5 warming scenario spans -86 percent to +388 percent. In other words the net effect is likely positive but too uncertain to distinguish from zero.]

Barker (2023) criticized the DJO12 assumption that countries can be grouped into fixed “poor” and “rich” categories based on their incomes many decades ago. He noted that many countries were once poor but became rich over time, and if this is considered the original temperature effects reported by Dell et al. became small and insignificant.

Berg et al. (2023) argued that countries shouldn’t be grouped into large Rich/Poor categories because they are too heterogeneous. They instead estimated country-specific temperature response coefficients then grouped countries with similar response coefficients into small panels. They separately estimated responses to global and idiosyncratic local temperature shocks to better identify the climate signal in weather data. Overall they found countries experiencing negative effects of warming on growth outnumbered those experiencing positive effects, but only temporarily: eventually the effects reverse such that about twice as many countries experience a net positive growth effect. They also found global (as opposed to local) temperature changes are much more likely to benefit growth in poor countries than rich ones. In a simulation to 2100 even using the extreme RCP8.5 scenario they computed the average global GDP loss would be only 1.9% compared to a scenario with no warming. That is, instead of the economy growing 400% it would grow 398%. The implication of Nordhaus’ analysis is that trying to prevent the warming would lead to far less than 398% growth.

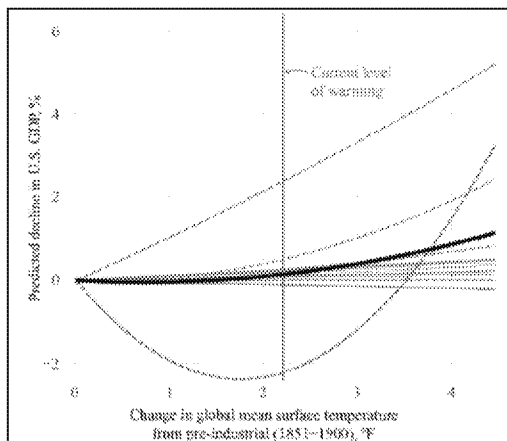
To summarize, economists have long considered climate a relatively unimportant factor in economic growth, a view echoed by the IPCC itself in the Fifth Assessment Report. Mainstream climate economics has recognized that CO₂-induced warming may have some negative economic effects but they are too small to justify aggressive abatement policy, and trying to “stop” or cap global warming even at levels well above the Paris target would be worse than doing nothing. An influential study in 2012 suggested that global warming would harm growth in poor countries but it has subsequently been found not to be robust. Studies that take full account of modeling uncertainties either find no evidence of a negative effect on global growth from CO₂ emissions or find poor countries as likely to benefit from it as rich countries.

The expectation that significant global warming would have a small impact on the U.S. economy was acknowledged quietly by the Biden Administration, even as the President was proclaiming a climate emergency. The following figure, from a 2023 OMB-CEA [HYPERLINK "<https://www.whitehouse.gov/cea/written-materials/2023/03/14/methodologies-and-considerations-for-integrating-the-physical-and-transition-risks-of-climate-change-into-macroeconomic-forecasting-for-the-presidents-budget/>"], shows the expected decrement in U.S. GDP as a function of temperature rise. The colored lines show the results of a dozen peer-reviewed published studies while the solid black line is their average. The figure could be summarized as “a few percent impact for a few degrees of warming”. Given that the economy’s

Commented [SK20]: It would be important to note that all of this work depends upon climate model projections at the regional and sub-regional scale. Since we’ll already have said in a prior chapter that the GCMs are practically worthless for that purpose, there needs to be a great big caveat here. As I phrased it in Unsettled, “taken with more than a pinch of salt”

Commented [RM21R20]: The inferences based on historical data don’t use climate model outputs. The projections do, but there the big influence is using RCP8.5.

annual growth rate is expected to be 1-2 percent, the impact of a warming globe is indeed negligible.



Need caption

13.2. Models of the Social Cost of Carbon

The Social Cost of Carbon (SCC) is a tool for quantifying the economic impact of carbon dioxide emissions, helping policymakers weigh the costs and benefits of climate policies. It estimates the damage caused by emitting one additional ton of CO₂, expressed in dollars. More formally, the SCC is the discounted present value of the current and future marginal loss of economic welfare due to an additional ton of CO₂ entering the atmosphere. On its own the SCC is not the appropriate price to attach to CO₂ emissions for the purpose of optimal emissions control but it can be converted into an optimal tax rate by scaling it by the Marginal Cost of Public Funds (MCPF). The theory behind this was first derived by Sandmo (1975) and has been reiterated many times since then by other economists working on the topic (e.g. Parry et al. 1999). The MCPF is the cost in terms of lost private economic welfare of raising public revenue by one dollar and always exceeds unity. If a jurisdiction does not use a carbon tax, this formula still indicates the upper bound on the amount emitters should spend on abatement options at the margin along the optimal policy path. Regulations should be imposed only insofar as they do not impose marginal abatement costs in excess of the optimal tax rate;

Commented [SK22]: Quite technical language

13.1.2 Estimating the SCC

Although the literature refers to "estimates" of the SCC, it is not estimated in the way other economic statistics are estimated. For instance, data on market transactions including prices and quantities can be used to estimate the current inflation rate or the growth rate of per capita

real Gross Domestic Product, and there are well-understood uncertainties associated with these quantities. But there are no market data available to measure many if not most of the marginal damages or benefits believed to be associated with CO₂ emissions, so these need to be imputed using economic models.

For example, an influential component of some SCC calculations is the perceived social cost associated with changed risk of future mortality due to extreme weather. There is no market in which people can directly attach a price to that risk. At best economists can try to infer such values by looking at transactions in related markets such as real estate or insurance, but isolating the component of price changes attributable to atmospheric CO₂ levels is very difficult.

Economists use IAMs to compute the SCC. Two of the best known IAMs are the Climate Framework for Uncertainty, Negotiation and Distribution ("FUND", Tol 1997) and Nordhaus' DICE. IAMs embed a stylized global climate model with a very simplified representation of the global economy, including a "damage function" or set of functions relating ambient temperature to local economic conditions. The assumptions embedded in the damage function will largely determine the resulting SCC.

One approach to developing a damage function is to begin with estimates of the costs (or benefits) of warming in specific sectors in countries around the world and aggregate up to a global amount. This was the approach used in FUND. An alternative approach is to develop a simple equation that penalizes global income according to a simple quadratic function of the average global temperature. This approach was used in DICE. In the case of the FUND model many hundreds of parameters had to be selected, whereas in DICE only three were needed and were originally chosen to assign a predetermined penalty (1.2%) to global output as of 3°C warming, with a quadratic term implying that damages grow with the square of the global average temperature anomaly. Barrage and Nordhaus (2024) recently changed the parameters to increase the penalty at 3°C to 1.6%, and added a discrete additional 1.0% GDP penalty at 3°C warming to account for "tipping points" (discrete large-scale environmental changes triggered by crossing a warming threshold) and a "judgmental adjustment" of 0.5% for excluded impacts at 3°C warming. Not surprisingly the newer version of DICE generates much higher SCC estimates than before.

The concepts of estimation and uncertainty do not readily apply to SCC calculations. By comparison, the question of whether precipitation has trended up or down along the South Carolina coast for the past hundred years can be addressed by collecting rainfall data, estimating a trend parameter and calculating statistical confidence intervals using methods with well-understood mathematical properties. In this way uncertainty can, in principle, be resolved by collecting more data and applying more accurate methods. But no amount of data collection can change the fact that many components of the SCC are unknown and rely on judgment and opinion based on knowledge of the underlying literature on the physical effects of climate change.

SCC calculations are thus best thought of as "if-then" statements: *if* the following assumptions hold, *then* the SCC is \$X per tonne. The list of 'if' statements includes the premise that the world's climate and economy work according to the representation in the IAM. One way this may fail to hold is in the timing of warming. Every IAM assumes a value of the Equilibrium Climate Sensitivity (ECS), controls the amount of warming that results from CO₂ emissions and can be freely varied for the purpose of generating a distribution of SCC values associated with

Commented [SK23]: Repeats material in the previous section. And again, where's the discount rate discussion?

Commented [SK24]: Do we need a more fulsome discussion of tipping points, which is an objection I often hear. [HYPERLINK "<https://www.pnas.org/doi/full/10.1073/pnas.2103081118>"] looked at eight different tipping points and still found only an additional few percent of damages - pretty persuasive to me

Commented [SK25]: Cynically, a corollary is that you can get any value you like by choosing your assumptions carefully. See, for example, the Stern Report ☹️

uncertainties over ECS. But as Roe and Baumann (2013) pointed out, time-to-equilibrium increases with the square of ECS, so an upward adjustment of the ECS parameter without an appropriate slowing down of the adjustment process can yield distorted present value damage estimates. In particular, the upper tail of warming associated with some commonly-used ECS distributions is physically impossible for even a thousand years into the future (Roe and Baumann 2013) yet in an IAM would be realized within a couple of centuries. Failure to align ECS with time-to-equilibrium will lead to an overestimate of the SCC value.

Commented [SK26]: Do the climate components of the IAMs account for the physical equilibration time of the climate system itself. Not inconsiderable on the timescales of interest?

13.2.2 Variations in the SCC

Every level of the IAM calculation includes assumptions, some more influential than others. Key assumptions include the following.

- **The discount rate:** Climate damages accrue over a long time horizon, and costs a century or two in the future need to be discounted to the present. The higher the discount rate the smaller the present value of future damages and vice versa. The discount rate represents the opportunity cost of spending money today rather than investing it and then having more to spend tomorrow. Some economists have argued for the use of very low discount rates in SCC calculations, resulting in policy recommendations that favor relatively large immediate investments in CO₂ emission reductions. The downside is that other investments could potentially earn a larger rate of return for society.
- **Equilibrium Climate Sensitivity:** IAMs have customarily employed a value of 3.0°C or 3.1°C following the IPCC's guidance. Empirically-estimated ECS values tend to be lower than this (see Chapter XX). Dayaratna et al. (2017, 2020, 2023) have shown that use of lower empirically-derived ECS values dramatically lower the resulting SCC estimate, even when low discount rates are used.
- **Damage function coefficients:** IAMs assume CO₂ and warming cause net harms that increase exponentially with temperature. More recently, IAMs have also incorporated effects from assumed potential climate tipping points. The FUND model took limited but explicit account of CO₂ fertilization effects in agriculture. Since the coefficients were selected prior the publication of the current evidence of global greening and the magnitude of benefits to crops from elevated CO₂ (see Chapters 2 and 10) the growth effects are likely understated. The DICE model (and others) did not explicitly include any CO₂ fertilization benefit, except to the extent it was taken into account in the literature consulted when picking the damage function coefficients. The damage function in FUND contains a region in which low warming yields net benefits in many regions, a finding which is supported by econometric models of warming and growth (Berg et al. 2023) and econometric simulations of agricultural changes (McKittrick 2025). The DICE damage function, by construction, rules out net benefits at any warming level.
- **Emission scenarios:** IAMs generate SCC estimates that increase as the pre-existing concentration of CO₂ increases. Consequently the value of damages later in the century will be higher, depending on the assumed baseline emissions over the coming decades.
- **Abatement costs:** IAMs represent the cost to the economy of reducing CO₂ emissions. If CO₂ emission reductions are assumed to be inexpensive, then the model will conclude that the optimal policy should aim for deeper emission cuts and vice versa.

Commented [SK27]: Finally! Should be mentioned earlier, I think

It is informative to ascertain whether SCC results are invariant to changes in some assumptions. But when different assumptions result in higher or lower SCC values, the change in the SCC value does not provide *prima facie* evidence about the validity of the assumptions. For example, in 2023 the US Environmental Protection Agency raised its preferred SCC value about 5-fold over the estimates it had issued ten years earlier. This is not because new data had been collected or better mathematical methods had been invented, but because new assumptions had been used, and the validity of those assumptions was a separate question. One was that global agricultural damages were far higher than previously assumed, based on an analysis in Moore et al. (2017). But as discussed in Section XX, McKittrick (2025) showed that Moore et al. (2017) had used a database in which half the CO₂ change observations were missing. When as many of those observations as possible were recovered from underlying sources and the analysis was rerun, the projected crop yield losses disappeared and turned into gains at all warming levels. Hence the portion of the EPA's SCC revision attributable to agricultural yield losses was unwarranted.

13.2.3 Evidence for low SCC

Chapter 2 reviewed evidence on climate change and greening, and Chapter 10 looked at climate change and US agriculture. Evidence shows that CO₂ fertilization has a stronger beneficial effect on agriculture than was known at the time that IAMs like DICE and FUND were parameterized. In particular Haverd et al. (2020) found the observed CO₂ fertilization rate has been almost double what had been predicted by crop models. Dayaratna et al. (2023) used the updated empirical ECS distribution estimate of Lewis (2022), which assimilates modern instrumental and paleoclimatic temperature records, and allowed for a 30 percent gain in the CO₂ fertilization benefit in the FUND model, and found that, even at a low discount rate of 2.5 percent, the median SCC as of 2050 is only \$18.67, with a 24 percent probability of the true value being negative. At a five percent discount rate the median SCC value is negative until the mid-2040s and at 2050 was only \$0.37 with a 49 percent probability of being negative. Thus, under reasonable assumptions a mainstream IAM using updated scientific inputs yields evidence consistent with the SCC not being significantly greater than zero.

It should also be noted that the SCC is focused on the social costs of CO₂ emissions from fossil fuel use. It does not measure the private marginal benefits to consumers and society from the availability of fossil fuels. Public willingness to pay for fuels of all types indicates the value to society of reliable, abundant fossil energy. Tol (2017) estimates that the private benefit of carbon is large relative to the social cost. This can be illustrated by noting that the price of a gallon of gas indicates the marginal value to the consumer of the fuel. Suppose we assume a relatively high Social Cost of Carbon of, say, \$75 per tonne. Deflated by a MCPF value of 1.5 that would result in a carbon tax of \$50 per tonne, which equates to about 44 cents per gallon of gas (Lavelle 2019). A pre-tax price of \$3.00 per gallon would imply the marginal social benefit of the fuel is nearly seven times the marginal social cost.

13.3. Summary

It is increasingly being argued that the SCC is too variable to be useful for policymakers. Cambridge Econometrics (Thoung 2017) stated it's "time to kill it" due to uncertainties. The UK and EU no longer use SCC for policy appraisal, opting for "target-consistent" carbon pricing (UK Department for Energy Security and Net Zero 2022, Dunne 2017). However the weaknesses of the SCC concept don't mean that other regulatory measures are inherently better or more efficient. Many climate regulations (such as electric vehicle mandates, renewable energy mandates, energy efficiency regulations and bans on certain types of home appliances) end up costing far more per tonne of abatement than a simple price on carbon emissions.

In summary, SCC estimates are highly uncertain due to unknowns in future economic growth, socioeconomic pathways, discount rates, climate damages, and system responses. The SCC is not intrinsically informative as to the economic or societal impacts of climate change. It provides an index connecting large networks of assumptions about the climate and the economy to a dollar value. Some assumptions yield a high SCC and others yield a low or negative SCC. The evidence for or against the underlying assumptions needs to be established independently; the resulting SCC adds no additional information about the validity of those assumptions.

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14. U.S. Vehicle-Based CO₂ Emissions and the Global Climate

The EPA's 2009 Endangerment Finding focused on CO₂ emissions from cars and light-duty trucks in the U.S. because Section 202(a) of Clean Air Act mandates the EPA to set emissions standards for motor vehicles if pollutants are found to endanger public health or welfare. Thus, the 2009 Endangerment Finding obligated the EPA to regulate emissions from new motor vehicles.

Two questions that naturally arise are: (1) How large a reduction in CO₂ emissions would result from such regulation? and (2) What would be the climate impact of such regulation?

The first question can be addressed using CO₂ emissions statistics from the EPA and the International Energy Agency (IEA). The second question can be addressed by the fact that the reduction in global warming is proportional to how much global emissions are reduced, keeping in mind that how much the CO₂ content of the atmosphere increases in any given year is the result of total global CO₂ emissions, not just U.S. emissions.

In 2022, the emissions from U.S. cars and light duty trucks totaled 1.03 billion metric tons of carbon dioxide (GtCO₂). This is only 2.8% of the 36.8 GtCO₂ of global energy-related emissions in 2022. If we were to take into account emissions from land use and cement production, that fraction would be even smaller, but for the purpose of the following calculation, it will suffice.

Even if all CO₂ emissions were eliminated from U.S. cars and light duty trucks in 2022, the impact on global warming would be less than 3%. Would such a tiny impact even be measurable in global temperature data? For the period 1979-2023, which has the most extensive global coverage of a variety of weather data types, warming trends from five global temperature datasets range from +0.163 deg. C per decade from the NCEP/NCAR R1 reanalysis dataset to +0.211 deg. C per decade for the ERA5 reanalysis dataset. The latter estimate is 29% larger than the former, indicating that a 3% reduction in the rate of global warming from eliminating U.S. vehicle CO₂ emissions would be an order of magnitude below the threshold of measurability. Given that global-average temperature is the most robust climate change metric, this means any other climate impacts (e.g. severe weather, floods, drought, etc.) from the elimination of U.S. vehicle CO₂ emissions would be even less significant.

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16. Glossary of Terms

2XCO₂: doubling of the atmospheric CO₂ content relative to pre-Industrial times, a commonly used baseline for addressing climate change. In 2025, atmospheric CO₂ concentrations were approximately 50% of the way to 2XCO₂.

ABATEMENT: in the context of pollution, the reduction of harmful impacts through pollution reductions

ACE (Accumulated Cyclone Energy): a statistical measure of a tropical cyclone's energy accumulated over its lifetime, calculated from a summation of the square of maximum sustained wind speeds

ACIDIFICATION: a commonly used term for the reduction in ocean pH from more alkaline to less alkaline values

AEROSOLS: tiny solid or liquid particles suspended in the air

ALKALINE: having a chemical pH greater than 7.0. The "opposite" of acidic, which means a pH less than 7.0

AMBIENT: relating to the immediate surroundings of something

ANTHROPOGENIC: created by humans

AR (IPCC Assessment Reports): periodic assessments published by the IPCC evaluating current knowledge of the climate system, global change, and associated issues. The most recent was AR6 in 2023.

BIOMASS: the total quantity or weight of organic matter in a given area or volume

CARBON: popular and widely used shorthand term for carbon dioxide

CMP (Coupled Model Intercomparison Project): The IPCC's organized effort to compare many different global ocean-atmosphere climate models when they are all forced with the same emissions scenario(s)

CONUS: the contiguous 48 U.S. states

DICE (Dynamic Integrated model of the Climate and Economy): An Integrated Assessment Model (IAM) developed by William Nordhaus in 1993.

DISCOUNT RATE: here, the rate used to convert future costs and benefits of environmental regulations into their present value. A high discount rate reduces the present value of future environmental benefits from regulating sooner; a low discount rate favors long-term benefits of regulating sooner.

DRY ICE: frozen carbon dioxide

ECONOMETRICS: the branch of economics concerned with the use of math and statistics in describing economic systems

ECS (Equilibrium Climate Sensitivity): The total amount of eventual global-average surface warming in response to a hypothetical doubling of the atmospheric CO₂ concentration compared to pre-Industrial levels.

EL NIÑO: the warm phase of ENSO, involving weaker upwelling of cold water off the South American coast and weaker Pacific trade winds.

EMISSIONS SCENARIO: An assumed scenario of future greenhouse gas emissions (or resulting atmospheric concentrations) based upon assumptions regarding global economic activity, the prevalence of fossil fuel use, and (sometimes) global carbon cycle model estimates of the rate of CO₂ uptake by land and ocean.

ENDANGERMENT FINDING (EF): the 2009 finding by the Administrator of the EPA that CO₂ emissions endanger human health and welfare

ENSO: El Niño – Southern Oscillation, a prominent natural climate fluctuation involving year-to-year variations in the upwelling of cold water off the equatorial coast of South America and associated strengthening or weakening of trade winds across the Pacific Ocean

FACE: (Free-Air CO₂ Enrichment) large-scale open-air studies that expose plants to elevated CO₂ levels, simulating future climate scenarios.

FOSSIL FUEL: a natural fuel such as coal or natural gas formed in the geological past from the remains of living organisms

FUND: An Integrated Assessment Model (IAM) developed by Richard Tol in 1997.

GBR (Great Barrier Reef): the world's largest coral reef ecosystem located off the northeast coast of Australia

GDP (Gross Domestic Product): total market value of all the final goods and services produced within a country's border, usually over one year

GHCN: the Global Historical Climatology Network, consisting of a time-varying number of globally distributed weather stations making hourly, daily, or monthly measurements of precipitation, temperature and sometimes snowfall and snow depth.

GLOBAL GREENING: the satellite-observed increase in greenness in most vegetated land areas observed since the early 1980s

GNP (Gross National Product): total market value of all the final goods and services produced by the citizens a country, usually over one year

GREENHOUSE EFFECT (GHE): the tendency for any planetary atmosphere containing greenhouse gases to be warmer in the lowest layers than if those gases did not exist.

GREENHOUSE GAS (GHG): an atmospheric gas that absorbs and emits infrared (IR) radiation, especially water vapor, CO₂, and methane.

HURST PHENOMENON: see long term persistence.

HYDROLOGY: the study of the movement of water, especially on land and the atmosphere

IAM (Integrated Assessment Model): a computerized tool that combines economics, climate science, and social sciences to provide quantitative relationships between human and Earth systems, helping to inform policy decisions

IEA: International Energy Agency

IPCC (Intergovernmental Panel on Climate Change): A panel of international experts and governmental representatives established by the United Nations and World Meteorological Organization in 1988 to provide governments at all levels with scientific information that they can use to develop climate policies

IR (Infrared): heat radiation that all solid objects and greenhouse gases emit by virtue of their temperature.

La Niña: the cool phase of ENSO, involving stronger upwelling of cold water off the South American coast and stronger Pacific trade winds.

LONG TERM PERSISTENCE (LTP, or HURST PHENOMENON): the tendency for natural systems such as precipitation, droughts, and floods to have persisting behavior over time, as opposed to random behavior, which impacts our interpretation of long-term trends in climate data

MAIZE: corn

MODEL: a computer code or collection of codes which quantify our knowledge of various processes and the interactions between those processes

MORTALITY: death or number of deaths, usually expressed for a specific population and period

NCA (National Climate Assessment): A periodic report mandated by the Global Change Research Act of 1990 summarizing the impact of climate change on the United States> There have been five NCA reports: NCA1 (2000), NCA2 (2009), NCA3 (2014), NCA4 (2017-18), and NCA5 (2023)

OECD (Organization for Economic Cooperation and Development): a specific list of 38 countries having a democratic system of government and free economic systems

PALEOCLIMATE: climate of the distant past, before modern weather instruments were widely used (typically pre-1850), necessitating the use of "proxy" measurements such as tree rings, ice core, pollen records, etc.

PDI (Power Dissipation Index): a statistical estimate of the accumulated destructive potential of a tropical cyclone over time, calculated as a summation of the cube of the maximum sustained wind speeds

PHOTOSYNTHESIS: the process by which plants grow, requiring carbon dioxide, water, and light at sufficiently warm temperatures (10 to 35 deg. C for optimal function)

PPM: parts per million, a measure of the concentration of a substance in (for example) the atmosphere

PRE-INDUSTRIAL: the historical period before which human greenhouse gas emissions were considered significant, usually assumed to be the mid-1700s

RADIATIVE FEEDBACK: a change in the balance between absorbed solar radiation and emitted infrared (IR) radiation, referenced to the top of the atmosphere, caused by changes in surface temperature

RADIATIVE FORCING: the change in the balance between absorbed solar radiation and emitted infrared (IR) radiation, referenced to the top of the atmosphere, caused by changes in greenhouse gases, anthropogenic aerosols, volcanoes, etc.

RCP SCENARIOS: Representative Concentration Pathways, different scenarios for future greenhouse gas emissions and their impact on the atmosphere, introduced in the IPCC's Fifth Assessment Report (AR5). RCP scenarios have a number label (e.g. RCP6.0) indicating how much radiative forcing they assume in 2100 relative to pre-industrial times, in Watts per sq. meter. RCP4.5 and RCP6.0 are intermediate scenarios, whereas RCP8.5 is an extreme scenario with very large future emissions of greenhouse gases.

RICARDIAN ANALYSIS: a method used in environmental economics to estimate the economic impacts of climate change, particularly on agriculture

SOCIAL COST OF CARBON (SCC): an estimate of the total economic damages, measured in dollars, caused by emitting one additional ton of CO₂ into the atmosphere

SSP SCENARIOS: Shared Socioeconomic Pathways, different scenarios for future greenhouse gas emissions and their impact on the atmosphere, introduced in the IPCC's Sixth Assessment Report (AR6). Some of the SSP scenarios are analogous to the older RCP scenarios, for purposes of continuity and comparison to earlier climate model assessments.

TC: tropical cyclone

TMAX: the daily maximum surface air temperature

TMIN: the daily minimum surface air temperature

TOA: top of atmosphere

TOXICOLOGY: the study of the adverse effects of chemical substances on living organisms.

TREND: usually, the linear regression slope fit to a time series of data, one of the most commonly used metrics to describe climate change over a long period of time

UHI (Urban Heat Island): the tendency for inhabited areas to be warmer than their rural surroundings, due to the replacement of natural land and vegetation with roads, parking lots, buildings, and waste heat sources.

USHCN: the U.S. Historical Climatology Network, consisting of quality-controlled temperature and precipitation data from 1,218 surface weather stations

17. About the authors

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Introduction

This document ~~originated had its origin in an initiative undertaken in late March 2025 when by Secretary Wright to assemble assembled an independent team~~asked the authors to write a brief report for him on issues in climate science relevant for energy policymaking, with particular focus on the question of whether carbon dioxide emissions ~~pose a danger to endanger~~ the US public. ~~The team~~ We authors of this report agreed on the usefulness of such a document and agreed to undertake the work on the condition that there ~~was to would~~ be no editorial oversight by the Secretary, the Department of Energy, or any other government personnel. This condition has been honored throughout the process and the writing team has worked with full independence.

The team began working in early April with a final submission deadline of May 28. Because of ~~t~~The short timeline and the technical nature of the material ~~meant we have not tried to produce that we could not comprehensively review of all topics. While the report is intended to be accessible for non-experts, we deliberately have omitted some introductory or explanatory material that can easily be accessed elsewhere. Nor have we attempted to survey entire literatures related to the topics selected for focus covered. The scientific and technical material herein is just a sample of the only samples vast literature on climate change but is, we believe, more than sufficient to establish our conclusions.~~

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The team writing this report was not involved in, nor briefed on, any ~~Administration plans or administrative processes~~ related to a potential challenge to the 2009 EPA CO₂ Endangerment Finding. During the writing of this report we received no information about the Administration's plan on that matter. We were asked, however, to include some information related to the role of US motor vehicles in global climate change, since that is an issue of relevance to the Department of Energy.

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6.7 Challenges, Uncertainties in Attributing Cause in Climate Change Attribution

6.7.1 Introduction

The detection and attribution process is concerned with assessing the causal relationship between one or more drivers and a responding system. The Intergovernmental Panel on Climate Change (IPCC) provides clear definitions for distinguishing between detection of climate change and attribution of cause. Detection and attribution in climate science, based on their Sixth Assessment Report (AR6). These terms are crucial for understanding climate change impacts and are used to assess whether observed changes are significant and what caused them. As defined by the IPCC AR6 WGI Glossary (IPCC, 2025):

Detection: "Detection of change is defined as the process of demonstrating that climate or a system affected by climate has changed in some defined statistical sense, without providing a reason for that change. An identified change is detected in observations if its likelihood of occurrence by chance due to internal variability alone is determined to be small, for example, <10%."

Attribution: "Attribution is defined as the process of evaluating the relative contributions of multiple causal factors to a change or event with a formal assessment of confidence."

The definition of detection emphasizes that both steps rely on statistical approach analysis. Detection focuses on whether changes are significant enough to stand out from natural variability/random variation without yet attributing causes regardless of cause.

The attribution process Attribution involves comparison of observed events to model-generated counterfactuals. Since experimentation on the climate is not possible attribution requires statistical inference to assess how much human activities, such as industrial GHG emissions, versus natural factors, like volcanic eruptions, contribute to explain observed changes, with a structured confidence level to reflect scientific certainty. Attribution methods requires the evaluation of the contributions of all external and internal drivers to of the system change are known and represented.

While the IPCC's definitions are clear, there are ongoing scientific debates around attribution methods, particularly especially in for attributing extreme weather events to climate change. The IPCC has long cautioned that methods to establish causality in climate science are inherently uncertain and ultimately depend on expert judgement. The Fourth Assessment Report: The Physical Science Basis (Hegerl et al., 2007) explained it as follows:

'Attribution' of causes of climate change is the process of establishing the most likely causes for the detected change with some defined level of confidence... unequivocal attribution would require controlled experimentation with the climate system. Since that is not possible, in practice attribution of anthropogenic climate change is understood to mean demonstration that a detected change is 'consistent with the estimated responses to the given combination of anthropogenic and natural forcing' and 'not consistent with alternative, physically plausible explanations of recent climate change that exclude important elements of the given combination of forcings' (IPCC, 2001)... The

approaches used in detection and attribution research described above cannot fully account for all uncertainties, and thus ultimately expert judgement is required to give a calibrated assessment of whether a specific cause is responsible for a given climate change.

The Fifth Assessment Report Working Group II makes the following statement: (W
Cramer et al., 2014):

“Two broad challenges to the detection and attribution of climate change impacts relate to observations and process understanding. On the observational side, high-quality, long-term data relating to natural and human systems and the multiple factors affecting them are rare. In addition, the detection and attribution of climate change impacts requires an understanding of the processes by which climate change, in conjunction with other factors, may affect the system in question.”

Because of the complexity of the causal chains in the climate system, investigation of these relationships is exceptionally challenging.

6.2 Attribution methods

The Intergovernmental Panel on Climate Change (IPCC) employs several attribution methods to assess the causes of observed climate changes, distinguishing between natural and human-induced factors. Below is a concise description of the key attribution methods that have been used by the IPCC:

Optimal Fingerprinting uses statistical-linear regression techniques to compare-explain variations in observed climate data with-as a weighted sum of climate model simulations run with and without anthropogenic forcings-of the responses to individual forcings (e.g., anthropogenic greenhouse gases, aerosols, natural forcings like solar variability). A regression model estimates the contribution of each forcing to observed changes, accounting for natural variability and model uncertainties. The data used in the regression model are weighted to try to minimize the influence of random noise and the estimation method is chosen to take account of climate model error.

Time Series Analysis examines-temporal changes-in climate variables to attribute trends to specific forcings. This approach compares long-term observed trends to model simulations with and without anthropogenic forcings. This method helps distinguish between short-term natural variability (e.g., El Nino) and long-term anthropogenic signals-exploits statistical differences between anthropogenic forcing and natural variability to see which one dominates observed temperatures, and also uses variations in the timing of changes to determine if causal dependence across data series can be inferred. *

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Process-Based Attribution focuses on understanding the physical mechanisms behind observed changes. This approach combines observations, climate models, and theoretical understanding to attribute changes in specific processes to forcings. This approach is often used for regional climate phenomena, such as monsoon changes or polar amplification

Extreme Event Attribution assesses the role of human influence in the likelihood of occurrence or intensity of extreme weather events (e.g. heat waves, droughts). Methods include:

- ~~Fraction of Attributable Risk quantifies how much anthropogenic climate change has altered the probability of an event~~
- Probabilistic Event Attribution uses large ensembles of climate model simulations to compare event-likelihood in a world with and without human influence ~~observed events to model-generated counterfactuals~~
- Storyline Approach examines the physical processes driving an event and evaluates how anthropogenic forcings may have modified those processes

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6.3 Attribution of global warming

Attribution statements for global warming in the three most recent IPCC Assessment reports are

AR4: "Most of the observed increase in global average temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic greenhouse gas concentrations." (IPCC, 2007)

AR5: "It is *extremely likely* that more than half of the observed increase in global average surface temperature from 1951 to 2010 was caused by the anthropogenic increase in greenhouse gas concentrations and other anthropogenic forcings together. The best estimate of the human-induced contribution to warming is similar to the observed warming over this period." (IPCC, 2013)

AR6: "The *likely* range of total human-caused global surface temperature increase from 1850–1900 to 2010–2019 is 0.8°C to 1.3°C, with a best estimate of 1.07°C. It is *likely* that well-mixed GHGs contributed a warming of 1.0°C to 2.0°C, other human drivers (principally aerosols) contributed a cooling of 0.0°C to 0.8°C, natural drivers changed global surface temperature by –0.1°C to +0.1°C, and internal variability changed it by –0.2°C to +0.2°C. It is *very likely* that well-mixed GHGs were the main driver of tropospheric warming since 1979." (IPCC, 2021)

The AR4 and AR5 attribution statements reference the warming ~~to~~ since the mid-20th century, the period when greenhouse gas emissions began rapidly increasing. The words "most" and "more than half" are deliberately imprecise, potentially ranging from 51 to 99% of the warming – presumably this imprecision is to account for structural uncertainties such as natural internal variability. The confidence level increases from *very likely* to *extremely likely* from AR4 to AR5.

The structure of the attribution statement in the AR6 is fundamentally different, referencing the warming to the period 1850-1900. The AR6 attribution statement is more precise numerically, but with a lower level of confidence at “likely” – the AR6 attributes essentially all of the warming to increases in greenhouse gases. The most confident statement from the AR6 relates to the tropospheric warming since 1979, using the words “main driver” and “very likely.”

There are ~~two~~^{three} areas of substantive criticism of the IPCC assessment of the causes of the recent warming: ~~inadequate assessment of natural climate variability, and inappropriate statistical methods, and substantial discrepancies between models and observations. The latter is discussed in Chapter 67, particularly section 64.~~ The other two factors are discussed herein. Both of these issues are relevant not only in context of the main policy-relevant statement of the IPCC concerning attribution of the recent warming, but also because the global warming attribution provides the basis for extreme event attribution

~~67.3.1~~ *Natural climate variability*

The IPCC AR6 states that natural external drivers since 1850-1900 have changed global surface temperature by -0.1°C to $+0.1^{\circ}\text{C}$, and internal variability has changed it by -0.2°C to $+0.2^{\circ}\text{C}$ – on average, having essentially no net impact on the warming since 1850-1900. This assessment of the contributions of natural variability has been disputed by a number of publications that question the magnitudes of the contributions from solar forcing and internal variability from the large-scale ocean circulations (R Connolly et al., 2021; W Soon, 2023).

If the Equilibrium Climate Sensitivity to CO_2 is low (~~SEE PREVIOUS CHAPTER~~Chapter 5), then natural climate variability becomes more important in the attribution of the recent warming. Further, if natural variability is higher, then estimates of the Equilibrium Climate Sensitivity from the historical period would be lower (Scafetta, 2023).

Solar variability

The IPCC AR5 concluded that the best estimate of radiative forcing due to Total Solar Irradiance (TSI) changes for the period 1750–2011 was 0.05 W/m^2 (Myrhe et al., 2014). The IPCC AR6 acknowledges a much larger range of estimates of changes in TSI over the last several centuries, stating that the TSI between the Maunder Minimum (1645–1715) and the second half of the twentieth century increased by $0.7\text{--}2.7 \text{ W/m}^2$, a range that includes both low and high variability TSI data sets (Gulev, 2021). However, the recommended forcing dataset for the CMIP6 climate model simulations used in the AR6 for attribution studies averages two data sets with low solar variability (Matthes, 2017).

While the IPCC AR6 shows a substantially greater solar impact than does the AR5, the overall impact on the climate was assessed to be small compared to anthropogenic forcing of climate change. However, the impact of solar variations on the climate is uncertain and subject to substantial debate – something that you would not infer from the IPCC assessment reports (Lockwood, 2012; Connolly et al., 2021).

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Exactly how TSI has changed over time has been a challenging problem to resolve. Since 1978,

there have been direct measurements of TSI from satellites. However, the data exhibit non-negligible inconsistencies, and interpreting any multi-decadal trends in TSI requires comparisons of observations from overlapping satellites. Substantial uncertainty exists in the TSI composites, particularly owing to a gap in coverage during 1989 to 1992 that prevented direct cross-calibrations between two successive satellites (N. Scafetta, 2019). This rather arcane issue of cross-calibration of two satellite records has profound implications. There are a number of several rival composite TSI datasets, disagreeing as to whether TSI increased or decreased during the period 1986–96 (the ACRIM gap; see Chapter 4). Further, the satellite record of TSI is used for calibrating proxy models, whereby past solar variations are inferred from sunspots and cosmogenic isotope measurements (Velasco Herrera et al., 2015).

There is substantial evidence for high solar activity in the second half of the 20th century (starting in 1959) and extending into the 1990's, before a decline in the early 21st century; this period is often termed the “Modern Maximum.” (Chatzistergos et al., 2023; Solanki et al., 2004; Usoskin et al., 2007). However, some scientists have concluded that it is not possible to be confident of any multi-decadal trend in TSI (Schmutz, 2021).

As a result of this uncertainty, some reconstructions for past values of TSI (since 1750) have low variability, implying a very low impact of solar variations on global mean surface temperature, whereas datasets with high TSI variability can explain more than 70% percent of the temperature variability since preindustrial times (Scafetta, 2013; Stefani, 2021). Hence, the choice of which TSI satellite record used in an analysis can substantially influence how much climate change is attributed to human versus natural forcings.

A review article on this topic was recently published in the journal *Research in Astronomy and Astrophysics* (Connolly et al., 2023). The article had 23 co-authors with a range of perspectives, but who were united by their agreement not to take the consensus approach of the IPCC. Rather, the paper emphasized where dissenting scientific opinions exist as well as identifying areas where there is scientific agreement. The authors found that the Sun/climate debate is an issue where the IPCC's consensus statements were prematurely achieved through the suppression of dissenting scientific opinions. **MOVE TO CH4**

There is growing evidence that other aspects of solar variability, which are referred to as solar indirect effects, amplify TSI forcing or are independent of TSI forcing. Scafetta et al. (2023) suggests that ~80% of solar influence on climate may stem from non-TSI mechanisms. Candidate processes include: solar ultraviolet changes; energetic particle precipitation; atmospheric-electric-field effect on cloud cover; cloud changes produced by solar-modulated galactic cosmic rays; large relative changes in the magnetic field; and the strength of the solar wind. Solar indirect effects are not included in climate models, although indirect methods of estimating these effects suggest significant influence. However, claims of non-TSI mechanisms influencing climate are uncertain and debated.

Natural variability of large-scale ocean circulations

Variations in global mean surface temperature are linked to recurrent large-scale variations in

ocean circulation patterns. These circulation patterns include the Atlantic Multidecadal Oscillation (AMO), the Pacific Decadal Oscillation (PDO) and the El Niño-Southern Oscillation (ENSO). These circulation patterns influence ocean heat uptake and heat distribution, and also influence atmospheric circulation patterns and cloud distributions. There is some debate as to whether these variations are strictly internal to the climate system, or whether this variability can have a solar/astronomical origin or can be influenced by large volcanic eruptions.

While climate models simulate the large-scale ocean circulations and internal climate variability, the simulated magnitude in the multi-decadal band is too low in most models relative to observations, and the phasing of the variability in long-term climate simulations is not synced with the actual, observed climate variations (Kravtsov et al. 2024). Averaging multiple simulations from climate models effectively averages out the internal variations, leaving only the forced climate variability (e.g., CO₂ forcing). With most of the modern warming beginning in the late 1970's, the recent 50-year warming is on the same time scale as the multi-decadal oscillations of the AMO and PDO.

Here are summary statements from the IPCC AR5 and AR6 reports:

"Decadal variability in the Pacific, associated with the PDO or IPO, contributes significantly to regional and global temperature trends, but the relative contributions of internal variability and external forcing are difficult to disentangle in CMIP5 simulations." (IPCC, 2013)

"Since AR5, there has been increased understanding of the role of internal variability, such as ENSO, PDO, and AMO, in modulating regional climate trends. However, limitations in simulating the exact timing and amplitude of these modes in CMIP6 models contribute to uncertainties in attributing observed changes to anthropogenic forcing (high confidence)." (IPCC, 2021)

The amplitude of the peak-to-trough impact of the multi-decadal oscillations on global temperatures has been assessed by the IPCC AR6: "The likely range of change due to internal variability is -0.2°C to +0.2°C (IPCC, 2021)." This implies a trough-to-peak change of 0.4°C. Over many centuries, any global temperature changes from the troughs and peaks will cancel out, with little to no net impact.

However, with a nominal timescale of 60-80 years for oscillations such as the AMO and PDO, the timing of the peaks and troughs can be confused with the secular trend. This becomes very relevant for attributing the warming for the 50 years since 1975, during which most of the warming has occurred. Even if climate models have the correct amplitude of the multidecadal oscillations, the timing of the peaks and troughs is not adequately simulated, with each model and individual ensemble simulating a different phasing. Once the simulations of the ensemble members and different models are averaged, the natural internal variability contribution is averaged out, effectively cancelling the role of natural internal variability in the attribution process.

The Great Pacific Climate Shift of 1976-1977 was a notable climatic event characterized by an abrupt change in the North Pacific Ocean's atmosphere-ocean system that interacted with global

climate patterns. This shift is closely associated with the Pacific Decadal Oscillation (PDO) that oscillates between warm and cool phases over decades. The 1976 shift marked a transition from a predominantly negative (cool) PDO phase (1947–1976) to a positive (warm) phase (1977 through 2000), with significant implications for global and regional climate patterns including the frequencies of El Niño and La Niña events. The Great Pacific Climate Shift coincided with the beginning of a period of accelerated global warming (REF TO A FIG OF GLOBAL TEMP ANOMALIES ELSEWHERE IN DOC) When the Great Pacific Climate Shift is accounted for in climate attribution analyses since 1950, it has been found that 40 percent or more of the warming in the second half of the 20th century was caused by natural internal variability (McLean et al., 2009; Tung and Zhou, 2013; Chykk et al., 2016; Scafetta, 2021).

67.3.2 Statistical methodsOptimal fingerprinting

Optimal fingerprinting is a statistical technique introduced by Allen and Tett (1999) that compares observed climate data with to climate model simulations to identify patterns (or "fingerprints") associated with human or natural influenceforcing. It involves taking a vector of observed climate changes, such as warming rates in locations around the world, and decomposing them into a weighted sum of "signals", which are analogues to the observations generated by climate models with different types of forcings. The weights are chosen using a regression method called Total Least Squares. The analysis commonly uses just two signals, one generated by models using only anthropogenic forcings and one using only natural forcings. If the estimated weighting coefficient attached to a signal is significantly different from zero, then that signal is said to be "detected". If it is close to 1.0, then the model generating the signal is said to be consistent with observations. If it is less than 1.0, then that implies the model signal for that forcing is too strong and needs to be scaled down, and vice-versa. Both the observed data and the signals are weighted using a model-generated estimate of patterns of randomness in the climate system so as, in principle, to put maximum weight on regions where natural variability is minimized.

Optimal fingerprinting has been heavily usedis the primary tool for attribution in the climate literature for establishing attribution. studies applying it have been cited thousands of times, and it has been prominently featured by the IPCC since the 2001 Third Assessment Report in 2004. One of its inherent weaknesses is that results depend on assumptions about the accuracy of climate models, especially regarding their representation of natural variability (IPCC AR5 Ch 10.2.3).

Additionally, a series of papers by McKittrick (McKittrick 2022a, 2022b, 2023, 2025) has challenged the statistical methods commonly used in optimal fingerprinting and broader attribution analysismethod, based onarguing that it is inherently unreliable and that commonly adopted-used practices in econometrics can provide more valid results. Statistical theory requires that for regression models to yield unbiased coefficients, a set of assumptions called the Gauss-Markov conditions must hold. These critiques highlight potential biases that could lead to over- or under-estimation of human influence on climate, and problems with the method that reduce confidence in the analysis results.

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McKittrick (2022a) challenged the methodology introduced by Allen and Tett (1999) for climate change attribution, which is a cornerstone of optimal fingerprinting. McKittrick argued that the Allen and Tett (1999) methodology violates key conditions of the Gauss-Markov theorem, particularly the requirement that the conditional expectation of errors must be zero. The violation leads, leading to potentially biased and inconsistent estimates of attribution fingerprinting coefficients, undermining the reliability of the method. Chen et al (2023) confirmed this analysis and argued that the method could yield unbiased results but only under very stringent assumptions. McKittrick (2022b) and (2023) raised a further concern that climate scientists—virtually alone among scientific disciplines—have used an estimation method called Total Least Squares (TLS) to estimate anthropogenic greenhouse gas signal coefficients, despite its tendency to be unreliable unless some strong assumptions hold that in practice are unlikely to be true. Under conditions which easily arise in optimal fingerprinting for climate attribution, TLS yields estimates with large positive biases. Thus, any study that has used TLS for optimal fingerprinting without verifying that it is appropriate in the specific data context has likely overstated the result.

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McKittrick (2025) presented an empirical example comparing the results of conventional optimal fingerprinting against methods drawn from mainstream econometrics, which are known to be valid for the specific application of signal detection. While the IPCC optimal fingerprinting method yields an anthropogenic signal coefficient close to 1.0 on a global temperature data set spanning 1900 to 2010, consistent estimation yields a coefficient around 0.4, which rises to about 0.65 on data spanning 1980 to 2010, implying the model response to greenhouse gases needs to be scaled down by about half to optimally match observations. The natural forcing signal coefficient, by contrast, is between 2.0 and 4.0, implying the climate model signals of natural forcing need to be scaled up two- to four-fold to match observed climate change. The fingerprinting coefficients estimated in McKittrick (2025), when used to scale the average sensitivity of the climate models used to generate the forcing signals in his dataset, imply a Transient Climate Sensitivity of 1.4°C, which matches the estimate by Lewis (2022) using a different estimation method and multiple independent data sets.

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While these analyses do not prove that all of the results from using these methods the IPCC optimal fingerprinting method are wrong, it does show that the basis on which they were believed to be correct is non-existent – hence reducing confidence in the results. McKittrick's work underscores the importance of statistical rigor in attributing climate changes and the need to bridge the gap between econometric and climatological approaches.

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7.3.3 Time series methods

The IPCC (AR5 WGI 10.2.2) drew attention to Alternative alternative approaches to of assessing causality between GHGs and climate have that emerged from the time series econometrics literature. They have the advantage of not depending on assumptions about the accuracy of climate models, but their disadvantage is they depend on assumptions about the data generating process underlying climate and forcing data that are not straightforward to test, specifically from methods used to infer directions of causality in finance and macroeconomic variables. The methods, now referred to as climate econometrics, use the tools of unit root testing, Granger

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causality and cointegration analysis, all of which are familiar in economics and finance and which are slowly being adopted in climate science. Time series analysis methods hold out the possibility of determining whether anthropogenic or natural forcings are the primary drivers of climate change without requiring the use of climate models, although key questions remain unsettled (e.g. Dergiades et al. 2016, Balcombe et al. 2019, Dagsvik et al. 2020, Razzak 2022, Dagsvik and Moen 2023). One method uses a technique called “Granger causality”, named after the economist Clive Granger. If two variables X and Y tend to move closely together over time it can be difficult to tell which one drives the other. Granger causality refers to the supposition that if knowing the current value of X significantly improves our forecasts of Y, but not the other way around, we can conclude X influences (“Granger-causes”) Y but not the reverse.

Granger causality modeling is a tool for determining directions of influence in data series that move together. “Granger causality” is a statistical, not a physical, concept. If knowing the current value of one variable significantly improves the forecast accuracy of another variable we can infer a causal connection exists; this is called Granger causality. The modeling tools, called vector autoregression, measure direct impulse-response patterns and feedbacks.

An application of Granger causality to the well-known Vostok ice core data revealed an important error by Al Gore in his documentary *An Inconvenient Truth*. Gore showed the data and drew attention to the coherence of temperature and CO₂ changes over a 440,000 year span and asserted that it, which he asserted implied, was due to CO₂ was the driver of driving temperature changes. But temperature changes can also affect atmospheric CO₂ levels. Davidson et al. (2015) examined the series and found that temperature Granger-causes CO₂ but not the other way around the reverse. In other words on the time scales represented in the Vostok data the coherence in the series is primarily due to the influence of temperature on CO₂ levels not the feedback going from CO₂ to temperature. In other words, while CO₂ and temperature are closely correlated over time, warming (cooling) appears to drive increases (decreases) in CO₂ levels on long time scales, but there is no evidence in the record that CO₂ changes drive subsequent warming or cooling.

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Another approach to determining causality between time series variables uses a concept called nonstationarity. It has a precise mathematical definition but for simplicity it can be thought of as the difference between a series that reverts to the same mean over time, thus having “short memory”, versus one in which past changes accumulate indefinitely implying the series has “long memory”. In economics the stock market is said to have long memory because what is known about the drivers of share value accumulates each day; traders do not forget each morning what they knew the day or before. Many economic variables are nonstationary in this sense. But climate variables are typically expected to be stationary or have short memory. Whatever causes today’s wind patterns is unlikely to be affected by the wind that blew on this day a year ago.

Nonstationarity leaves mathematical patterns in time series called unit roots. Some authors have proposed that a fingerprint of anthropogenic climate change would be the presence of unit roots in global temperature data. The reasoning is that the climate system should normally be stationary, but if nonstationary economic activities like GHG emissions drive the climate, it will show up as unit roots in temperatures.

It should be noted that finding unit roots in global temperatures can indicate a direction of causality between GHG forcing and climate, but it does not on its own measure whether the effect is large or small.

There have been many published tests for the presence of unit roots in temperatures as well as tests for deeper patterns of nonstationarity in GHG and whether they match those in temperatures. Unfortunately tests for unit roots are very sensitive to minor variations in how the tests are constructed and conflicting results exist in the literature. Some authors report positive results which would support GHG causality (e.g. Dargiades et al. 2016) while others find either unit roots are not present, indicating lack of GHG causality (Halecombe et al. 2019, Razzak 2022, Dagsvik et al. 2020, Razzak 2022, Dagsvik and Moon 2023) or are present but in a form inconsistent with GHG forcing (Beenstock et al. 2012).

In summary, while a causal link from CO₂ to temperature is plausible due to the underlying physics, evidence based solely on statistical methods is unclear. Statistical analysis based on Granger causality indicates that over very long time scales CO₂ levels respond to temperature changes but do not drive them. On recent time scales it is not possible at this time to conclude an unambiguous unit root signal, which would correspond GHGs driving climate, exists in global temperature data. In summary, the main statistical methods for attributing causation in climate data are optimal fingerprinting and time series analysis. Applications of the Allen and Tett (1999) optimal fingerprinting method dominate the attribution literature and have underpinned past IPCC conclusions, but results depend on the accuracy of climate models and the method has recently been criticized as inherently biased. Time series methods do not depend on climate models but require assumptions of their own and have generated results that have thus far not converged on a consensus.

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7.4 Extreme event attribution (EEA)

The IPCC AR6 provides an ambiguous assessment of the role of global warming in the historical record of extreme weather and climate events. Chapter 11 of WG1 states (Seneviratne et al., 2021):

“Evidence of observed changes in extremes and their attribution to human influence (including greenhouse gas and aerosol emissions and land-use changes) has strengthened since AR5, in particular for extreme precipitation, droughts, tropical cyclones and compound extremes (including dry/hot events and fire weather). Some recent hot extreme events would have been extremely unlikely to occur without human influence on the climate system.”

By contrast, Chapter 12 of WG1 (Table 12.12) paints a different picture – presumably, the expert judgment of different groups of authors for the two chapters came to different conclusions (Ranasinghe, 2021):

- High confidence in an increase in extreme heat events in tropical regions where observations allow trend estimation and in most regions in the mid-latitudes, medium confidence elsewhere
- Medium confidence in a decrease in extreme cold events in Australia, Africa and most of northern South America where observations allow trend estimation
- No evidence of emergence in the historical period of a change in river floods, heavy precipitation, drought, fire weather, severe wind storms, and tropical cyclones

While the overall issue of detecting changes in extreme weather events and their attribution remains ambiguous, most of the activity in this area relates to the attribution of single extreme weather events. The most prominent effort is the World Weather Attribution (WWA; worldweatherattribution.org), which is an international research initiative that focuses on extreme event attribution: analyzing how climate change influences the likelihood and intensity of extreme weather events. The approach used by the WWA runs large ensembles of regional climate models to compare the event in today's climate, versus a pre-industrial counterfactual climate without human-caused warming.

WWA plays a significant-prominent role in linking extreme weather to climate change, ~~using rapid probabilistic attribution to inform~~ and its press releases attract considerable public and policy discussions.

However, the WWA's tendency to promote non-peer-reviewed reports/findings, funding ties, open admission that they shape their analyses to serve purposes of litigation and other methodological challenges have sparked controversies, with critics questioning the robustness and impartiality of its conclusions (Pielke Jr. 2024). Despite these issues, WWA's work continues to shape climate science and media narratives. Technical criticisms of the approach include: neglect of a formal detection process; an implicit assumption that 100% of the post-industrial warming is caused by CO₂; and failure to adequately account for natural internal climate variability.

Because EEA is relatively new many basic methodological issues have yet to be settled in the expert literature. An important challenge is the lack of data. ~~Beyond the issue raised by event attribution approaches, there exist major challenges to the detection step—a step that is commonly skipped, contra to the IPCC's established detection and attribution approach. Extreme events are by definition rare. Many analyses of extreme event types (including the US National Assessment Reports) only evaluate data since 1950 or 1970. However, as emphasized by Chapter xxx's, many of the worst extreme weather and climate events in U.S. history occurred prior to the first half of the 20th century and including in the early 19th century. And if paleoclimate reconstructions are also considered, it becomes very difficult for an event to pass the detection thresholds of exceeding what is expected from natural variability, particularly if a reasonably sized geographic region is considered.~~

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Another challenge is defining the event under study. There is a longstanding literature in statistics and econometrics on the challenge of analyzing data with outliers. The issue arises because a data series establishes a probability distribution defining the expected range of observations. If an

outlier is observed it might indicate that the underlying process giving rise to the data distribution has changed (which in the weather context would mean a climatic change has been detected) or that the underlying process has multiple regimes each with a different probability distribution, in which case observing an outlier simply means we were temporarily in a different regime, but the system itself was unchanged. If a time series contains only a single outlier event at the end of the series it is not possible to determine which model is the correct one (Chen and Liu 1993). For instance, there might be an "ordinary" weather regime that yields a distribution of summer daytime highs in a particular coastal region, and a second "heatwave" regime that kicks in when an inland blocking event occurs, which yields a temperature distribution centered 15°C higher than the first one. A day with temperatures 13°C above normal would either be an extreme heat anomaly under the first regime or a somewhat cool event under the second, and we have no way in this case of knowing on statistical grounds which view is correct.

Visser and Petersen (2012) and Sardeshmukh et al. (2015) both point out that different distributions may fit observed data equally well but yield very different implications about the likelihood of a specific weather event. Visser and Petersen argue that, in view of the deep uncertainties of extreme weather analysis drawing a connection between individual events and global climate change should be avoided. Furthermore the existence of an outlier at the end of a data series poses the problem that estimates of the event probabilities will be biased whether the outlier is included or excluded (Berby et al. 2020). Methods to eliminate the bias have not yet been established, leading some experts (e.g. Miralles and Davison 2023) to argue that in settings in which a data series contains a single extreme event at the end, estimation of a return period for the extreme event will be so biased and uncertain it should be avoided altogether.

~~Beyond the issues raised by event attribution approaches, there exist major challenges to the detection step—a step that is commonly skipped, contra to the IPCC's established detection and attribution approach.~~

~~Extreme events are by definition rare. Many analyses of extreme event types (including the US National Assessment Reports) only evaluate data since 1950 or 1970. However, as emphasized by Chapter six, many of the worst extreme weather and climate events in US history occurred in the first half of the 20th century and the 19th century. And if paleoclimate reconstructions are also considered, it becomes very difficult for an event to pass the detection thresholds of exceeding what is expected from natural variability, particularly if a reasonably sized geographic region is considered.~~

In spite of these concerns, the US is presently considering something like the WWA, which is being investigated by a NASEM Panel on Attribution of Extreme Weather and Climate Events and their impacts (NASEM, 2025).

~~Extreme weather events can be extreme in terms of the magnitude of individual events, the frequency of events crossing some threshold, or clustering of extreme events. It needs to be acknowledged that extreme events are by definition rare, and short historical records (even century-long records) are insufficient for formulating meaningful statistics about return times and event likelihood.~~

~~Case~~ ~~A case~~ studies from two recent recent high impact extreme events in the U.S. ~~are~~ is provided to illustrate the challenges and ambiguities in attributing the frequency and intensity of extreme weather events to human-caused warming.

4.1 Case study – 2021 Western North America heat wave

The 2021 Western North America heat wave was an extreme heat wave that affected much of Western North America in late June 2021. In particular, surface temperature records were set in Portland, OR (116°F; previous record 107°F) and Seattle, WA (108 °F; previous record 103°F) (Mass et al., 2024).

The WWA team garnered international headlines for their analysis and provided the following attribution statements (WWA, 2021; Philip et al., 2022):

- Based on observations and modeling, the occurrence of this heatwave was virtually impossible without human-caused climate change.
- The event is estimated to be about a 1 in 1000-year event in today's climate.
- The event would have been at least 150 times rarer without human-induced climate change.
- This heatwave was about 2°C hotter than it would have been if it had occurred at the beginning of the industrial revolution (when global mean temperatures were 1.2°C cooler than today).

But an important caveat to the first claim is that other researchers concluded, based on historical weather data, that while a heat wave of the magnitude observed was indeed virtually impossible without anthropogenic climate change, it was also virtually impossible *with* climate change. Beres-Hickey (2022) noted “these temperatures were virtually impossible under any previously experienced meteorological conditions, with or without global warming.” McKinnon and Simpson (2022) stated “the most likely explanation remains that the weather event itself was ‘bad luck.’” The 2023 Oregon Climate Assessment (Fleischman 2023) concluded that the heat dome would have formed even without climate change and “There is no evidence that the highly unusual combination of weather features that drove the heat dome were made more likely by climate change, and climate models do not project an increase in the frequency of high-pressure ridges over the Pacific Northwest” (Fleischman 2023 p. 49).

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Mass et al (2024) summarizes the proximate sequence of compound events leading to the heat wave. There was a record-breaking midtropospheric ridge over the Pacific Northwest, forced by a tropical disturbance in the western Pacific. This produced record-breaking midtropospheric temperatures, strong subsidence in the lower atmosphere, low-level easterly flow that produced downslope warming on regional terrain and the removal of cooler marine air, and an approaching low-level trough that enhanced downslope flow. The event occurred at a time of maximum solar insolation, and drier-than-normal soil moisture. Using a storyline approach, Mass et al. assessed that there is no trend in drought and dry soils in the Pacific Northwest; there is no evidence of global warming producing stronger ridges of high pressure, and no observed trend in heat waves or record temperatures in the region. They concluded that although anthropogenic warming may have contributed as much as 2°F to the magnitude of the event, there is little evidence of further amplification of the event from increasing greenhouse gases.

A more sophisticated statistical analysis of a model-based attribution study of this heat wave was conducted by Bercos-Hickey et al. (2022). Because this event is a far outlier and far above the bounds of Generalized Extreme Value distributions fitted from historical data, they concluded that estimates of return times, quantitative changes in event magnitude and frequency, and probability of the extreme temperatures such as provided by the WWA are not accurate and should be interpreted as having low confidence. They found that hindcast attribution methods using an ensemble of regional climate models, combined with Pearl (2009) causal inferences, can provide limited and conditional information about the magnitude of the human influence on this heatwave – they provided a more highly constrained estimate that human activities caused a $\sim 1.4^{\circ}\text{C}$ – 1.8°F increase in the daily maximum temperatures.

Zeder et al. (2023) also concluded that the methods employed by Philip et al. (2022) tend to overstate the rarity of extreme heat waves, leading to a biased perception of the effect of climate change on the heatwave event: “The tendency to overestimate the return period of observed extreme heatwave events may fuel the impression that seemingly impossible heatwave extremes are currently clustering at an unprecedented rate.”

The 2021 Western North America heatwave was a rare and unprecedented compound weather event, that broke century-old temperature records by as much as 9°F . While there is little doubt that anthropogenic global warming contributed to the probability and magnitude of the extreme temperatures, while the WWA team received worldwide publicity for their rapid attribution claims blaming anthropogenic climate change, subsequent peer-reviewed analysis showed that the rare uniqueness of the event challenges quantifying this influence by traditional event attribution methods. event was not made more probable by global warming.

Van Oldenborgh et al. (2022) summarize the challenges of attributing heat waves. A warming climate means that a fixed temperature threshold is passed more frequently, hence the probability of extreme heat increases. Land use changes, vegetation change, irrigation, air pollution, and other changes also drive changes in local and regional heatwave trends. Sometimes these factors enhance heatwave intensity, but they can also counteract the effects of climate change. Temperature variability is unrealistic represented in many climate models and does not stand up to standard quality assessments. Accordingly, heatwave attribution remains unreliable and a major scientific challenge in many regions. This is particularly true when the moisture budget is not well simulated, and where land surface changes have occurred.

6.4.2 Case study: Hurricane Harvey misfall. I DON'T LOVE THIS EXAMPLE. DELETE? MAYBE SOMETHING ELSE?

Hurricane Harvey made landfall in southern Texas on August 21, 2017 as a Category 4 hurricane. The primary damage from Harvey occurred after the storm had been downgraded to a tropical storm and stalled near the coastline with a stationary front along the TX/LA border, dropping torrential and unprecedented amounts of rainfall over Texas. Hurricane Harvey provides an informative example of the challenges of detection for a rare event, and also the complexity of extraneous factors that can influence such an event.

The first issue to consider is detection. Harvey set the record for most amount of rainfall from a continental U.S. landfalling hurricane (60 inches), going back at least to the 1880's when comprehensive records begin (Landsea, 2017). The previous top four rainfall producers for U.S. landfalling tropical cyclones were 48 inches in Texas from Tropical Storm Amelia (1938), 45 inches in Florida from Hurricane Emily (1950), 45 inches in Florida from Tropical Storm Claudette (1979), and 40 inches in Texas from Tropical Storm Allison (2001). Looking more broadly at North Atlantic hurricanes that made landfall in Central American and the Caribbean, Roth (2017) identifies the following landfalling hurricanes that produced more rainfall than Harvey: 100 inches in Cuba from Hurricane Flora (1963), 96 inches in Jamaica from the November 1969 Hurricane, 63 inches in Nicaragua from Hurricane Mitch (1998), and 60 inches in Mexico from Hurricane Wilma (2005). Hurricane Harvey's rainfall arguably meets the detection criteria, whereby an attribution analysis is justified, although Harvey's rainfall was far from unprecedented from historic Atlantic hurricane landfalls.

In addressing the attribution of extreme rainfall from a landfalling hurricane, there are several factors leading to excessive rainfall that aren't associated with temperature. Slow motion of the hurricane near landfall can lead to high amounts of local rainfall (e.g. Wilma 2005, Harvey 2017). Mountains/hills near the coast magnify rainfall potential due to forced upslope flow (e.g. Mitch 1998). Upper level troughs and cold fronts can lead to excessive rainfall (e.g. Floyd 1999). Horizontally large tropical cyclones have larger rain footprints, which can lead to excessive rainfall owing to the longer time frame over which rainfall falls at any one location.

The WWA attribution analysis of Hurricane Harvey's rainfall (GJ van Oldenburgh et al, 2017) found that human-caused climate change made the heavy rainfall associated with Hurricane Harvey roughly three times more likely and 15% more intense.

Several publications based on model simulations have concluded that as much as 40% of the rainfall from Hurricane Harvey was caused by human-caused global warming (Emanuel 2017; River and Wehner 2017). The rationale for these assessments was that prior to the beginning of summer of 2017, sea surface temperatures in the western Gulf of Mexico exceeded 86°F and ocean heat content was the highest on record in the Gulf of Mexico (Trenberth et al, 2018). However, El Niño-Southern Oscillation (ENSO) and Atlantic circulation patterns contributed to this elevated heat content.

Landsea (2017) summarizes the arguments for more rainfall from tropical cyclones traveling over a warmer ocean. Simple thermodynamic calculations suggest that the amount of rainfall in the tropical latitudes would increase by about 4% per °F of sea surface temperature increase. Examining a 300-mile radius circle for nearly all of the rain implies that about 10% more total hurricane rainfall for a warming of 2.25°F. The Gulf of Mexico has warmed about 0.7°F since 1960. Even if it is assumed that all of this warming is due to manmade global warming, this suggests that roughly 3% of hurricane rainfall today can be reasonably attributed to manmade global warming. Hence, only about 2 inches of Hurricane Harvey's 60 inches can be linked to manmade global warming.

Aryal et al. (2018) examined the contribution of North Atlantic hurricanes to flooding and heavy rainfall across the continental U.S. Their analysis does not point to any significant change in the magnitude or frequency of floods. They found that the North Atlantic Oscillation (NAO) plays a

~~significant role in hurricane-related extreme rainfall along the U.S. East Coast, while ENSO is not strongly linked to the hurricane-related precipitation in Texas.~~

~~With regards to the rainfall associated with landfalling hurricanes, there is no clear signal of increasing rainfall owing to the complexity of the factors contributing to hurricane-induced rainfall.~~

6.5 Summary

There is an ongoing scientific debate around attribution methods, particularly in attributing extreme weather events to climate change. The IPCC has long cautioned that methods to establish causality in climate science are inherently uncertain and ultimately depend on expert judgement.

There are two areas of substantive criticism of the IPCC assessment of the causes of the recent warming: inadequate assessment of natural climate variability, and inappropriate statistical methods.

Detection of extreme weather events is challenged by their rarity, requiring a long data set and a choice of region and spatial scale to evaluate their occurrence against the background of natural weather and climate variability.

The most robust attribution statements for an extreme event relate to an incremental change (e.g. a temperature change in degrees or percent change in rainfall). Statements related to return times, quantitative changes in event magnitude and frequency, and probability of the extremes are not accurate owing to an inadequate amount of data, and are made with low confidence. There is no evidence in a change of weather or climate regime patterns from increasing greenhouse gases that would amplify or dampen extreme weather events, beyond basic thermodynamic considerations.